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NAVORD REPORT 6806

RADIOGRAPHY OF CAST HIGH EXPLOSIVES (U)

15 MARCH 1960

U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

78

NAVORD Report 6806

RADIOGRAPHY OF CAST HIGH EXPLOSIVES (U)

Prepared by:

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ABSTRACT: Data on the radiographic techniques for the inspection of cast high explosives at 150, 250 and 2000 Kvp are presented in tabular and graphical form to assist the radiographer in the selection of a suitable technique. Sensitivity limits for various conditions of explosive encasement have also been determined. Inert materials for use as penetrameters have been investigated and nylon was found to be satisfactory.

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The purpose of this report is to present information on radiographic techniques for the inspection of cast high explosives. It is intended as a practical guide for use with radiographic specifications.

This work was performed by the Nondestructive Analysis Group of the Physics Research Department of the Naval Ordnance Laboratory and by the Research and Development Division of the Naval Weapons Station, Yorktown, Virginia, for ReU3a and QC of the Bureau of Ordnance (Bureau of Naval Weapons). That portion of the work accomplished by the Naval Ordnance Laboratory was funded under Task NO 301-664/43004/01040.

Two other documents are also in preparation, (1) OD 15533, Reference Radiographs for the Inspection of Cast High Explosives, and (2) A Method for Controlling the Quality of Radiographic Inspection of High Explosives.

The work on this task is Unclassified.

JOHN A. QUENSE'
Captain, USN
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S. J. RAFF
By direction

ACKNOWLEDGMENT

The authors wish to thank Mr. Baxter C. Carr, Jr., Mr. Robert B. Smoot, and the members of the Research and Development Division of the Naval Weapons Station, Yorktown, Virginia, for their cooperative efforts on this task. Their skill and ability to produce the required explosive samples made possible the successful completion of this task assignment.

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RADIOGRAPHY OF CAST HIGH EXPLOSIVES

INTRODUCTION

1. The performance requirements of explosive ordnance are becoming more stringent. The evolution of missile warheads with shaped charge characteristics has placed added emphasis upon the inspection of the explosive load. Although radiography has been used extensively for the nondestructive inspection of explosive ordnance, very little technical data has been published on the X-ray absorption characteristics of explosive materials.[1/] The object of this investigation was to determine the absorption characteristics of the common cast explosives to different X-ray energies and to determine the capabilities and limitations of X-ray inspection as applied to explosive ordnance.

PREPARATION OF MATERIALS

2. The explosives used in this investigation are listed in Table I along with the density and aluminum content of the material. It can be seen that the material density increases with the increase in aluminum content. Since the absorption of X-rays by material is a function of density (also atomic number) it is to be expected that these explosives will differ in absorption characteristics. In order to obtain experimental data special castings were made from these explosives. Each material was vacuum cast in 1-1/2-inch thick slabs which were individually X-ray inspected to assure sound castings. Enough slabs were made from each material so that approximately 17 inches could be attained by stacking.

3. One slab of each type explosive was used as a penetrameter. A number of flat-bottomed holes with the diameter twice

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1/ OP 1681 Handbook of Ordnance Radiography, Bureau of Ordnance, 7 June 1946.

the depth were drilled into these slabs. Figure 1 illustrates the arrangement and dimensions of the holes. Sensitivity was calculated in the usual manner, where the depth of the hole is expressed as a percentage of the total thickness X-rayed.2/3/

EXPERIMENTAL PROCEDURE

4. Experience has shown that technique and sensitivity curves present the maximum information concerning radiographic technique for a particular material and X-ray energy. Such curves were obtained by exposing various thicknesses of the explosive material (3/4" to 17") to X-ray energies of 150, 250 and 2000 Kvp for varying periods of time so that film densities from 0.5 to 6.0 were obtained. The exposure time was then correlated with the film density for each thickness as shown in Figure 2. From this graph the technique curve was obtained, see Figure 3.

5. The penetrameter was included in each exposure and radiographic sensitivity was determined from the smallest hole perceptible. This information was plotted on a graph of thickness versus exposure time and points of equal sensitivity were connected to form the sensitivity loop shown in Figure 4. Since the technique curve and sensitivity loop have an identical abscissa and ordinate, they are combined to form the technique and sensitivity curve, Figure 5.

TECHNIQUE AND SENSITIVITY CURVES

6. Technique curves were made for the materials listed in Table I at 150, 250 and 2000 Kvp and 2 million volts constant potential. A comparison of the data revealed a similarity in the X-ray absorption characteristics of Comp B and TNT, the two materials which do not contain aluminum. A similarity was also noted between H-6, HBX-1 and HBX-3, materials containing aluminum. Because of the similarities in absorption characteristics, Comp B and H-6 were selected as representative of each group.

7. The technique and sensitivity curves for Comp B and H-6 with fine and medium grained film at 150 Kvp, 250 Kvcp and 2000 Kvp are shown in Figures 6 through 17. Technique

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2/ MIL-STD-271A - Military Standards for Nondestructive Testing Requirements for Metals.

3/ ASTM E7-141-59T.

curves are shown in Figures 18 through 21 for two million volts constant potential. Although the technique curves for the two materials differ at each of the above energies the sensitivity values are almost identical. Radiographically, these materials are characterized by a very wide 2% sensitivity loop which encompasses a film density range of 0.5 to 6.0. Because 2% was obtained over such a wide range, the 1% loop was considered more informative. This loop extends through a density range of approximately 0.75 through 5.0, however, the finest sensitivities were obtained with film densities between 3.0 and 4.0.

8. Table II presents the sensitivities which were obtained for different thicknesses of Comp B and H-6 at the various X-ray voltages. Equivalent sensitivities were obtained for Comp B and H-6 with both slow and medium speed film. The values for less than five inches of explosive indicates that sensitivities at least this fine can be obtained, however, the difficulty of drilling small flat-bottomed holes prevented the determination of the lower limit of radiographic sensitivity for these small thicknesses. That greater differences in sensitivity were not obtained between the fine and medium grained film is thought to be due to the comparatively large penetrameter increments.

EQUILIBRIUM HALF VALUE LAYERS AND ABSORPTION COEFFICIENTS

9. The equilibrium half value layer is defined as the thickness of absorber that will reduce the intensity of an X-ray beam to one-half. It is often used to determine the exposure time for some thicknesses of material. The number of half value layers of material to be radiographed and the intensity of the X-ray source determines the X-ray intensity transmitted through the absorber and received by the film. The exposure time can then be estimated from the dose response of the film.

10. From the technique curves the equilibrium half value layers for each of the X-ray voltages were determined and are presented in Table III. A comparison of the half value layers reveals very little difference between the explosive materials at 2000 Kvp (2 million volts half wave rectified) and 2 Mev (2 million volts constant potential). As expected, at 250 Kvcp and 150 Kvp there is an appreciable difference between the materials containing aluminum and those containing no aluminum.

11. Because the differences are small between the half value layers of the various types of explosives at high energies, a common radiographic technique should be suitable. However,

at lower energies the larger differences between the half value layers of the various explosives necessitates a separate technique for each material.

12. The linear absorption coefficient for each material can be determined at the different X-ray voltages by utilizing the half value layer data in the following equation

$$\mu = \frac{.693}{HVL} \tag{1}$$

where μ = linear absorption coefficient
HVL = half value layer

Table IV lists the linear absorption coefficients for each of the explosive materials at the different energies.

RADIOGRAPHIC EFFECT OF STEEL CONTAINERS

13. In ordnance application explosives are usually encased in steel containers. The walls of these containers lengthen the exposure time and affect the quality of the image. To determine the extent of these effects, technique and sensitivity curves were made for H-6 at 250 Kvcp and 2000 Kvp with various thicknesses of steel added to each side of the explosive. Figures 22, 23 and 24 show such curves at 250 Kvcp with 1/8", 1/4" and 1/2" of steel added to each side of the explosive. Similar curves at 2000 Kvp with the addition of 1/4" and 3/4" of steel are shown in Figures 25 and 26. These curves were compared to those made at the same energies but without the addition of steel, Figures 14 and 16. It was found that the greatest effect was increased exposure time; there was little change in radiographic sensitivity. In determining radiographic sensitivity only the thickness of explosive was considered.

14. As shown in Figures 22 through 26, a 1% sensitivity loop was obtained for all of the conditions described. Table V lists the sensitivities obtained with each thickness of explosive for each set of conditions.

15. The increase in exposure time cannot readily be predicted by utilizing the half value layer of the steel since it is the first rather than the equilibrium half value layer which applies to composites. It was possible however from a review of the experimental data to derive exposure factors to compensate for the steel walls. For example, at 250 Kvcp the

addition of 1/4" of steel increases the exposure time by a factor of four. The exposure factors for the addition of the various thicknesses of steel to both sides of the explosive were obtained by comparing the technique curves for H-6 with and without steel absorbers, Figure 27.

INERT PENETRAMETERS

16. Military specifications[2/] require that penetrameters be made of a material radiographically similar to that being examined; this is usually done by fabricating the penetrameter from a material of approximately the same composition as the object being examined. In the case of explosives this creates a safety hazard since small pieces of explosive materials are easily broken or mislaid. Also, it is not desirable to handle such material in its "raw" state. For these reasons, penetrameters for use with explosives should be made from a radiographically similar but inert material. From a consideration of the atomic numbers and densities, magnesium and nylon were chosen for study; these materials are durable, easily machined and are commercially available.

17. The sensitivities obtained with magnesium and explosive penetrameters under identical conditions at 250 Kvcp are presented in Table VI. The sensitivities obtained with magnesium are consistently lower than those obtained with explosive penetrameters. This misleading difference in sensitivity makes magnesium undesirable as a substitute material for explosives.

18. The sensitivities obtained with nylon and explosive penetrameters under identical conditions with Comp B and H-6 at 250 Kvcp and 2000 Kvp are presented in Table VII. Although the sensitivities differed under some conditions, the difference is not large and does not lead to false indications of satisfactory sensitivity. For these reasons nylon is a satisfactory substitute penetrameter material. It is recommended that nylon penetrameters be used for production inspection of explosives.

SUMMARY

19. This study of the X-ray absorption characteristics of cast explosives revealed a similarity between the explosives which contain aluminum and also a similarity between those which do not contain aluminum. Comp B and H-6 were found to be representative of these two groups. It was determined that the explosives which contain aluminum have a greater absorption for X-rays than those which do not contain aluminum.

20. Sensitivities better than 2% were obtained with all thicknesses of explosive materials at each of the X-ray energies considered. Sensitivities of 1/2% were obtained in the thickness range of 8 to 17 inches at 2000 Kvp with the finest sensitivities being obtained at film densities between 3.0 and 4.0.

21. The addition of steel walls to the explosive materials degrades the radiographic sensitivity. However, sensitivities finer than 1% were still obtained at 2000 Kvp for all thicknesses of explosive between 3-1/2" and 17" with 3/4" of steel added to each side of the explosive. Exposure factors were derived from the experimental data which enabled a correction in the exposure time to compensate for the attenuation by steel walls of varied thickness.

22. Nylon was found to be suitable as a penetrameter material for cast explosives. Although the sensitivities obtained with nylon penetrameters are not in complete agreement with those obtained with explosive penetrameters, the difference is small and not misleading.

TABLE I

Explosive Materials

Explosives	Material Density	Aluminum Content (percent)
TNT	1.65	0
Comp B	1.72	0
HBX-1	1.76	17
H-6	1.80	21
HBX-3	1.89	35

TABLE II

Sensitivities for Different Thicknesses of Comp B and H-6

Thickness of Explosive (inches)	Sensitivity Obtained at 150 Kvp (percent)	250 Kvcp (percent)	2000 Kvp (percent)
2.3	0.85	0.85	1.7
3.8	1.05	1.05	1.05
5.3	0.75	0.75	0.75
8.3		0.72	0.48
11.3		0.53	0.35
14.3			0.42
17.3			0.35

NOTE: Equivalent sensitivities were obtained for Comp B and H-6 with both slow and medium speed film.

TABLE III

Half Value Layers for Explosive Materials
at Different Energies (inches)

Material	X-ray Voltage 150 Kvp	250 Kvcp	2000 Kvp	2 Mev
TNT	1.45	1.60	3.0	3.2
Comp B	1.40	1.55	2.9	3.0
HBX-1	1.2	1.45	2.95	3.0
H-6	1.15	1.5	2.95	2.95
HBX-3	1.1	1.4	2.9	2.95

TABLE IV

Linear Absorption Coefficients for Explosive Materials
cm^{-1}

Material	X-ray Voltage 150 Kvp	250 Kvcp	2000 Kvp	2 Mev
TNT	.188	.171	.091	.085
Comp B	.195	.176	.094	.091
HBX-1	.228	.188	.0925	.091
H-6	.237	.182	.0925	.0925
HBX-3	.248	.195	.094	.0925

TABLE V

Radiographic Sensitivities for H-6 with Steel Walls of Various Thicknesses

Thickness of Explosive (inches)	Thickness of Steel Added to Each Side				
	0"	1/8"	1/4"	1/2"	3/4"
	% Sensitivity obtained at 250 Kvcp				
2.3	0.85	1.7	1.7	1.7	--
3.8	1.05	1.05	1.05	1.05	--
5.3	0.75	0.75	0.75	0.75	--
8.3	0.48	0.72	0.72	0.72	--
11.3	0.35	--	0.88	--	--
	% Sensitivity obtained at 2000 Kvp				
2.3	1.7	1.7	1.7	--	1.7
3.8	1.05	1.05	1.05	--	1.05
5.3	0.75	0.75	0.75	--	0.75
8.3	0.72	0.72	0.72	--	0.72
11.3	0.53	--	0.88	--	--

TABLE VI

Sensitivity Comparison of Magnesium and Explosive Penetrameters--250 Kvcp - H-6

Thickness of Explosive (inches)	Explosive Penetrameter Sensitivity (percent)	Magnesium Penetrameter Sensitivity (percent)
2.3	1.28*	1.19
3.8	1.23	1.05
5.3	1.22	1.05
8.3	1.12	0.97

*All of the sensitivities listed above are the average obtained from several films

TABLE VII

Sensitivity Comparison of Nylon and Explosive Penetrameters

Thickness of Explosive (inches)	Comp B		H-6	
	Explosive (percent)	Nylon (percent)	Explosive (percent)	Nylon (percent)
250 Kvcp				
2.3	1.7	1.7	1.7	1.7
3.8	1.1	1.1	1.1	1.1
5.3	0.8	0.8	0.8	0.8
8.3	0.7	1.0	0.7	0.7
2000 Kvp				
2.3	1.7	1.7	0.9	0.9
3.8	1.1	1.1	1.1	1.1
5.3	0.8	0.8	0.8	0.8
8.3	0.5	0.5	0.5	0.7
11.3	0.5	0.5	0.4	0.4
14.3	0.4	0.6	0.4	0.4
17.3	0.4	0.4	0.4	0.5

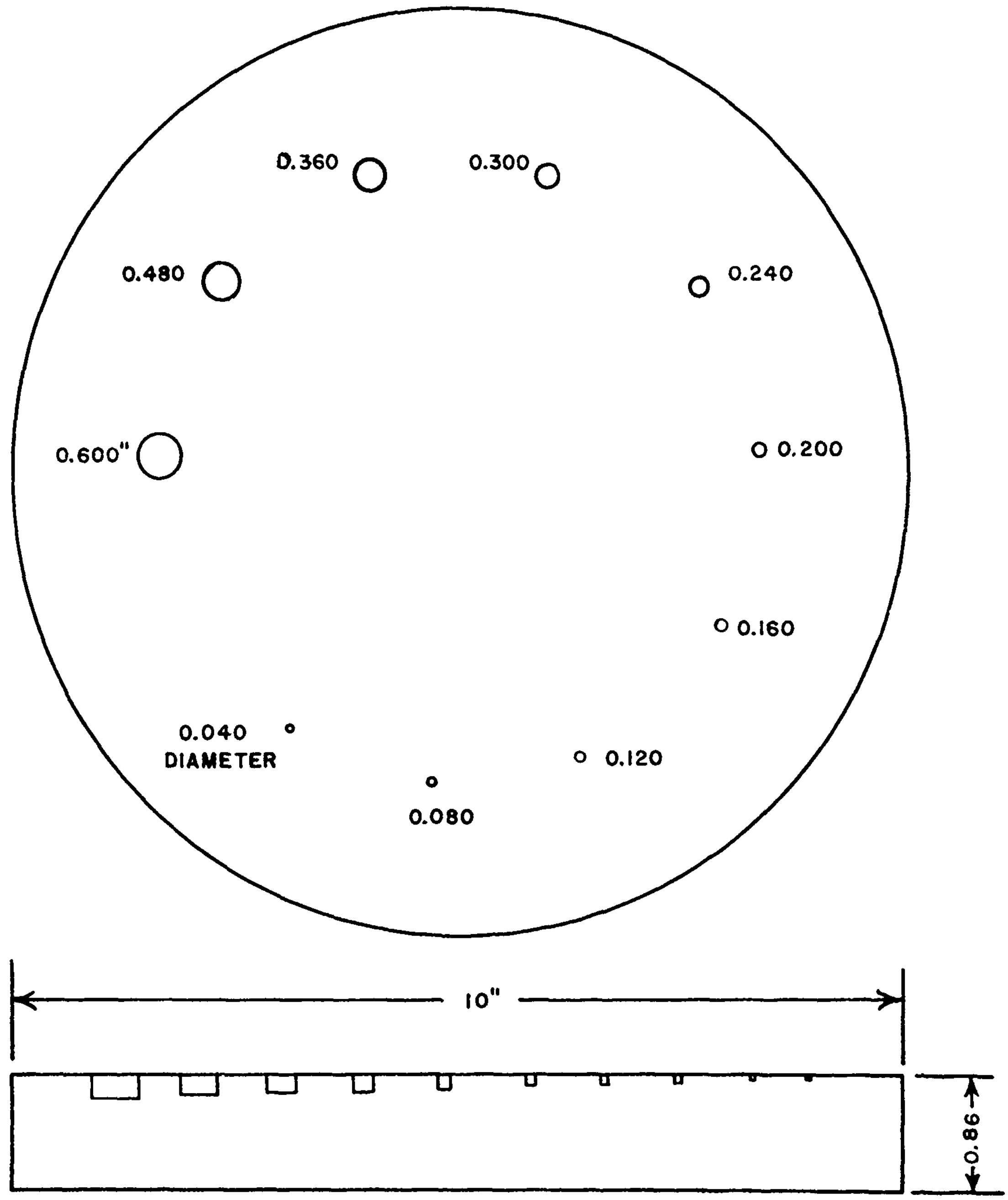

FIG. 1 THE CAST EXPLOSIVE PENETRAMETER

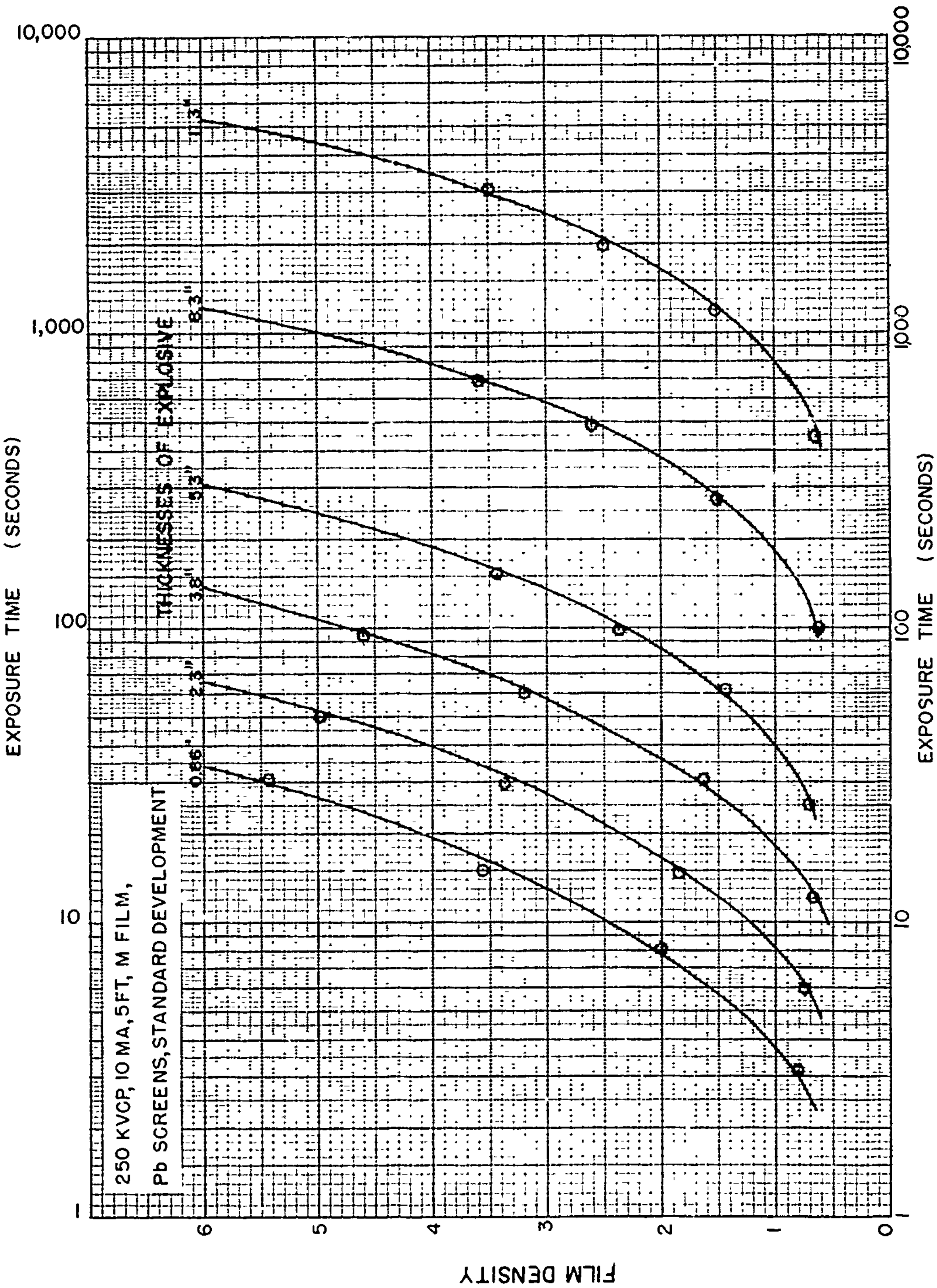

FIG. 2 DENSITY — EXPOSURE TIME FOR HBX-3

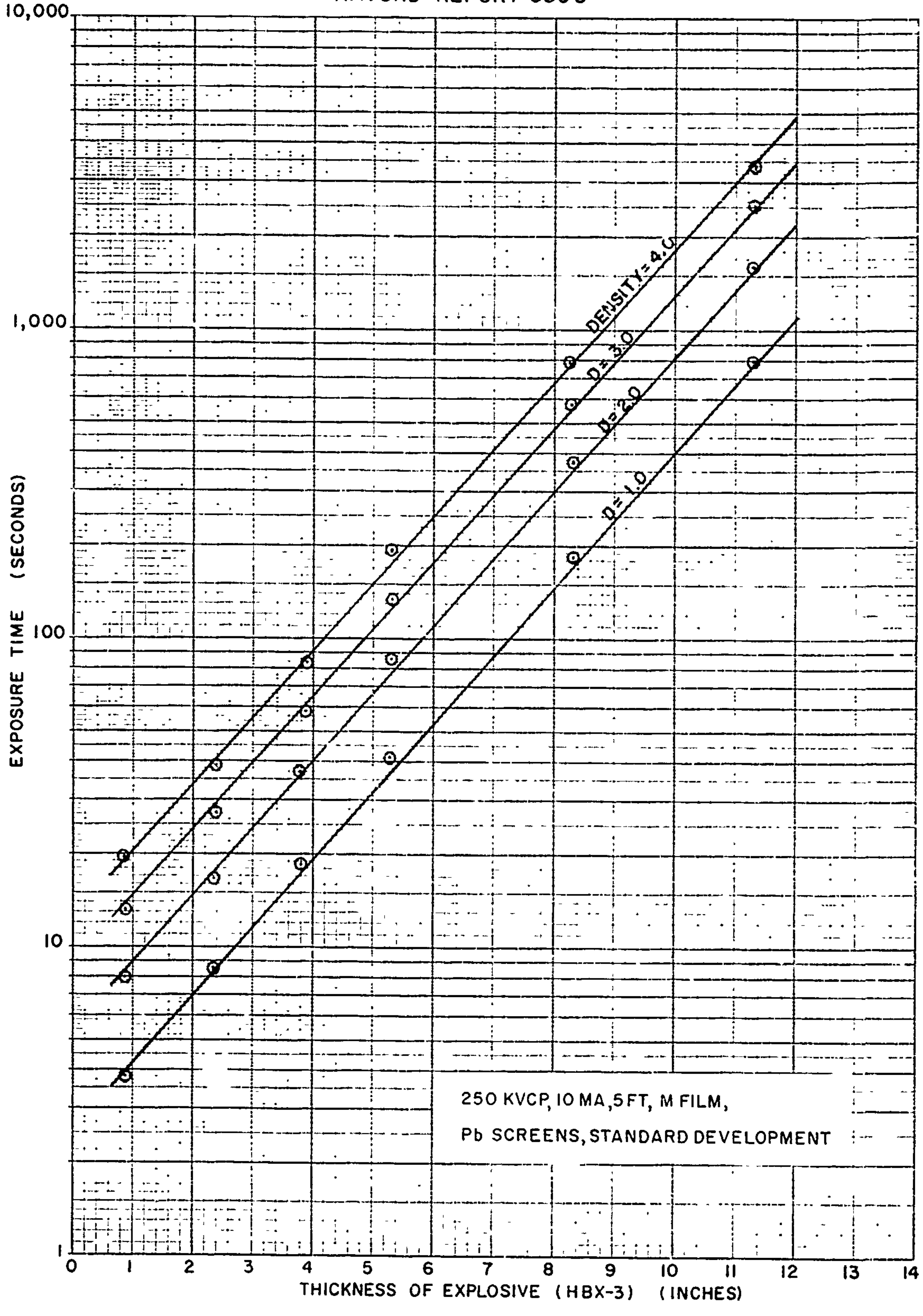

FIG. 3 TECHNIQUE CURVE FOR HBX-3

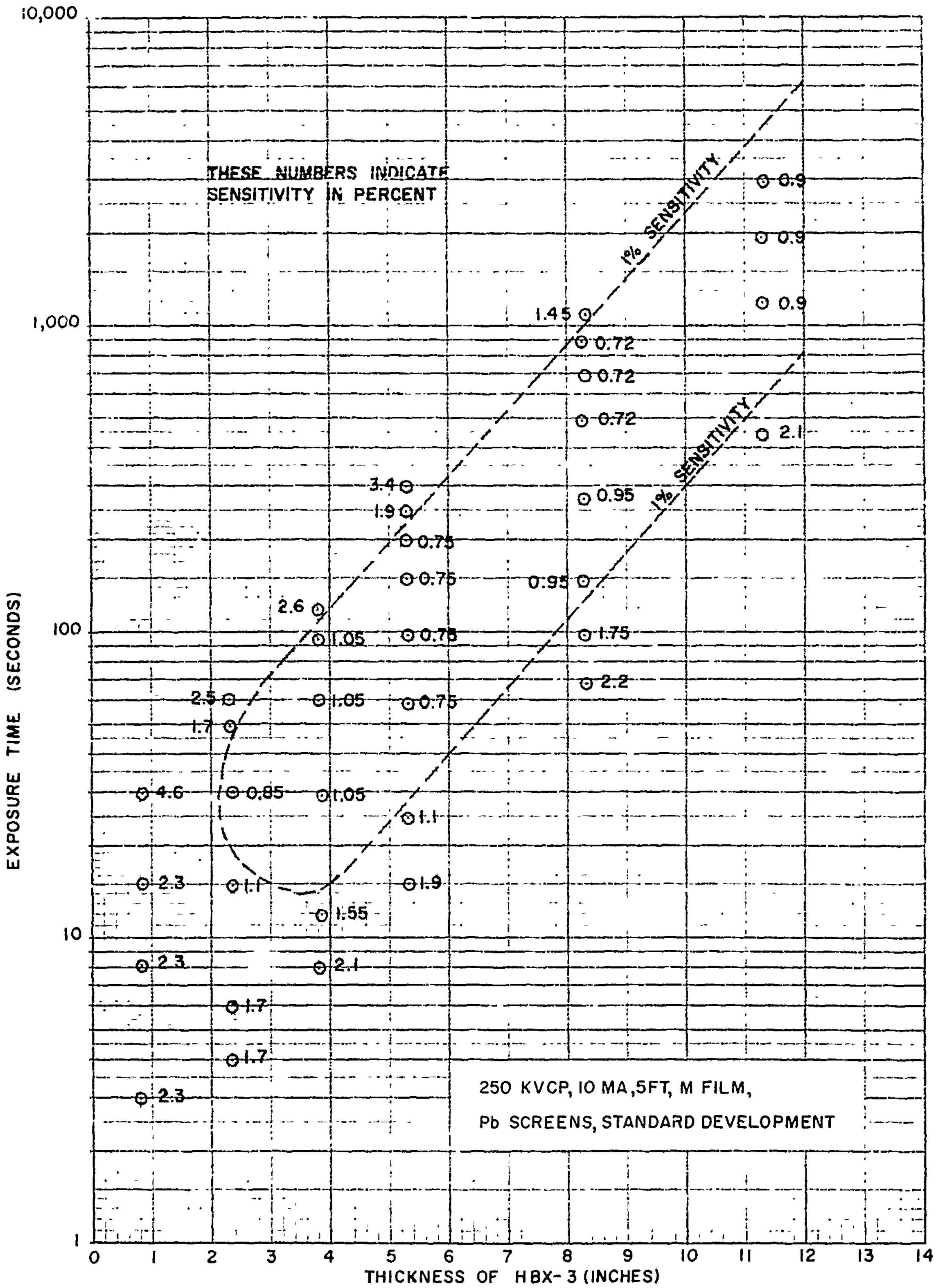

FIG. 4 SENSITIVITY LOOP FOR HBX-3

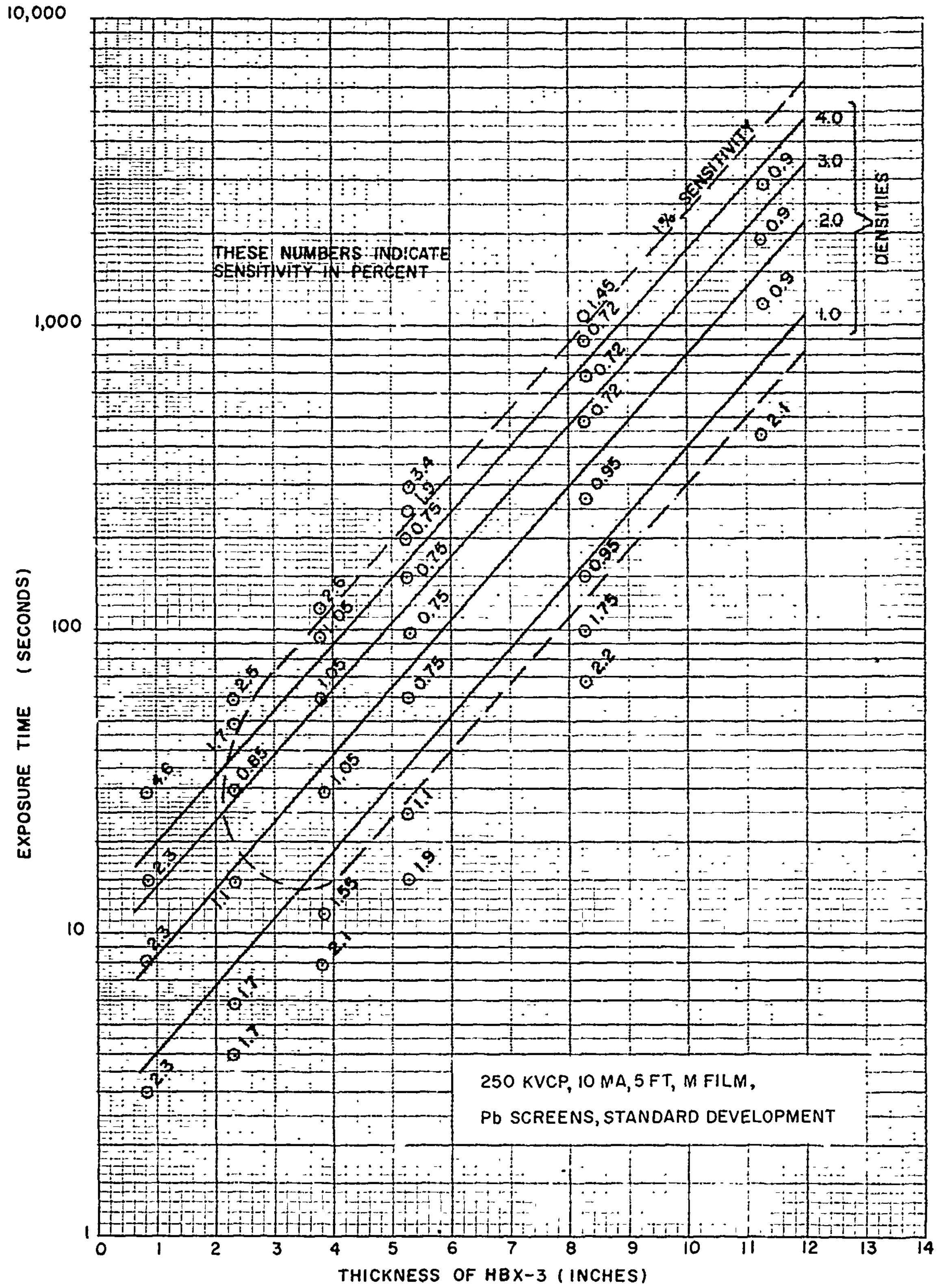

FIG. 5 COMBINED TECHNIQUE & SENSITIVITY CURVE FOR HBX-3

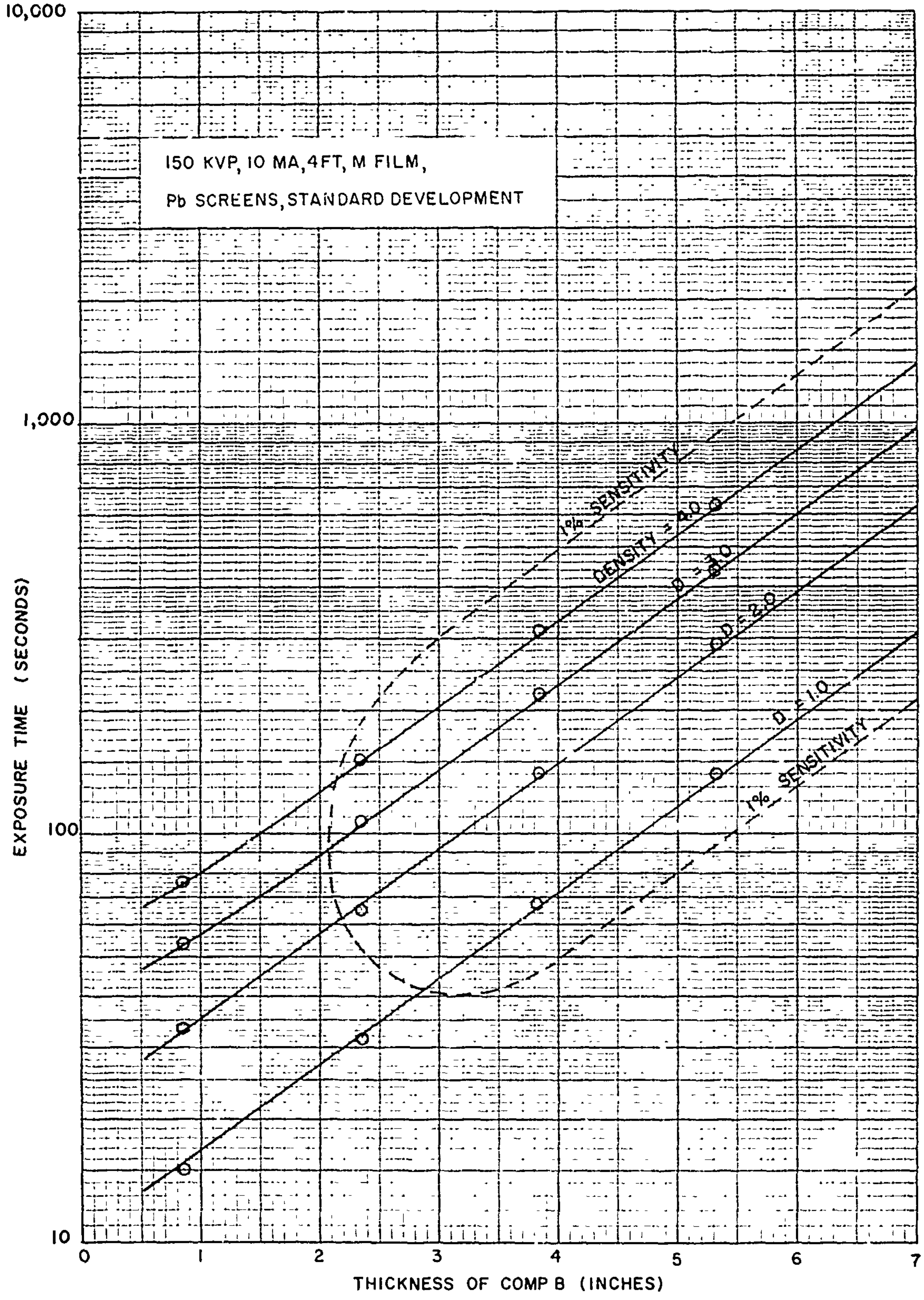

FIG. 6 TECHNIQUE & SENSITIVITY CURVE FOR COMP B

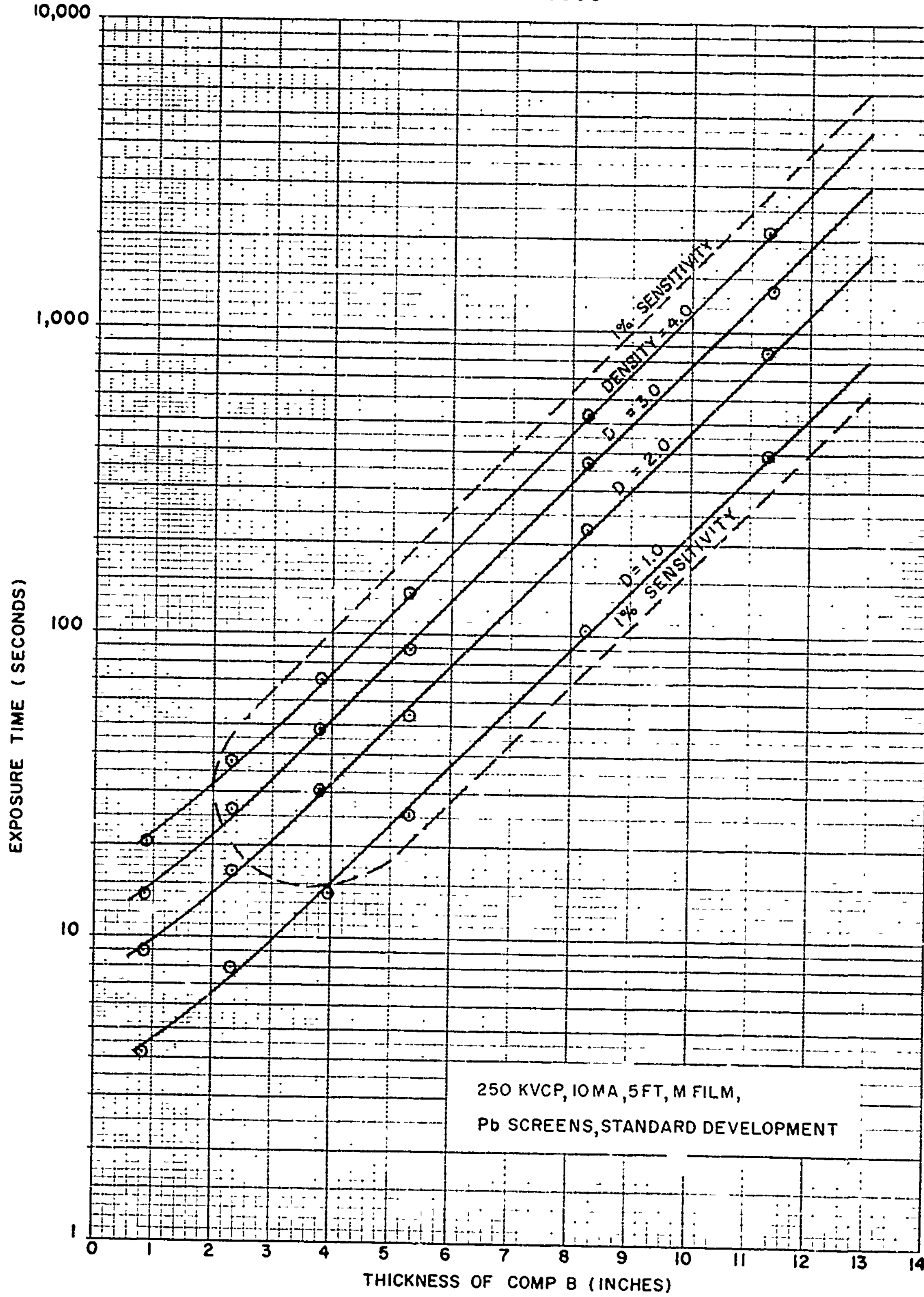

FIG. 7 TECHNIQUE & SENSITIVITY CURVE FOR COMP B

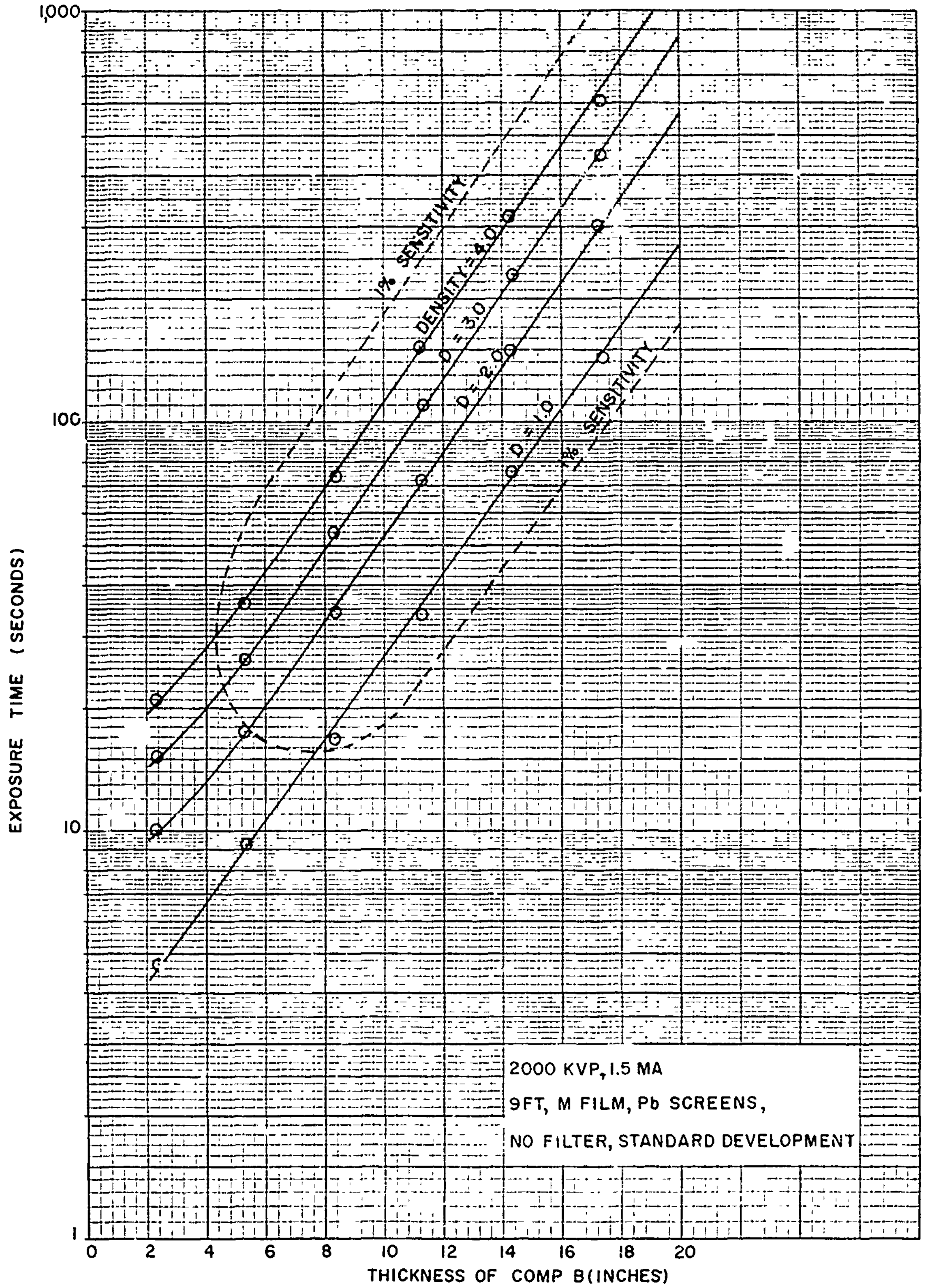

FIG. 8 TECHNIQUE AND SENSITIVITY CURVE FOR COMP B

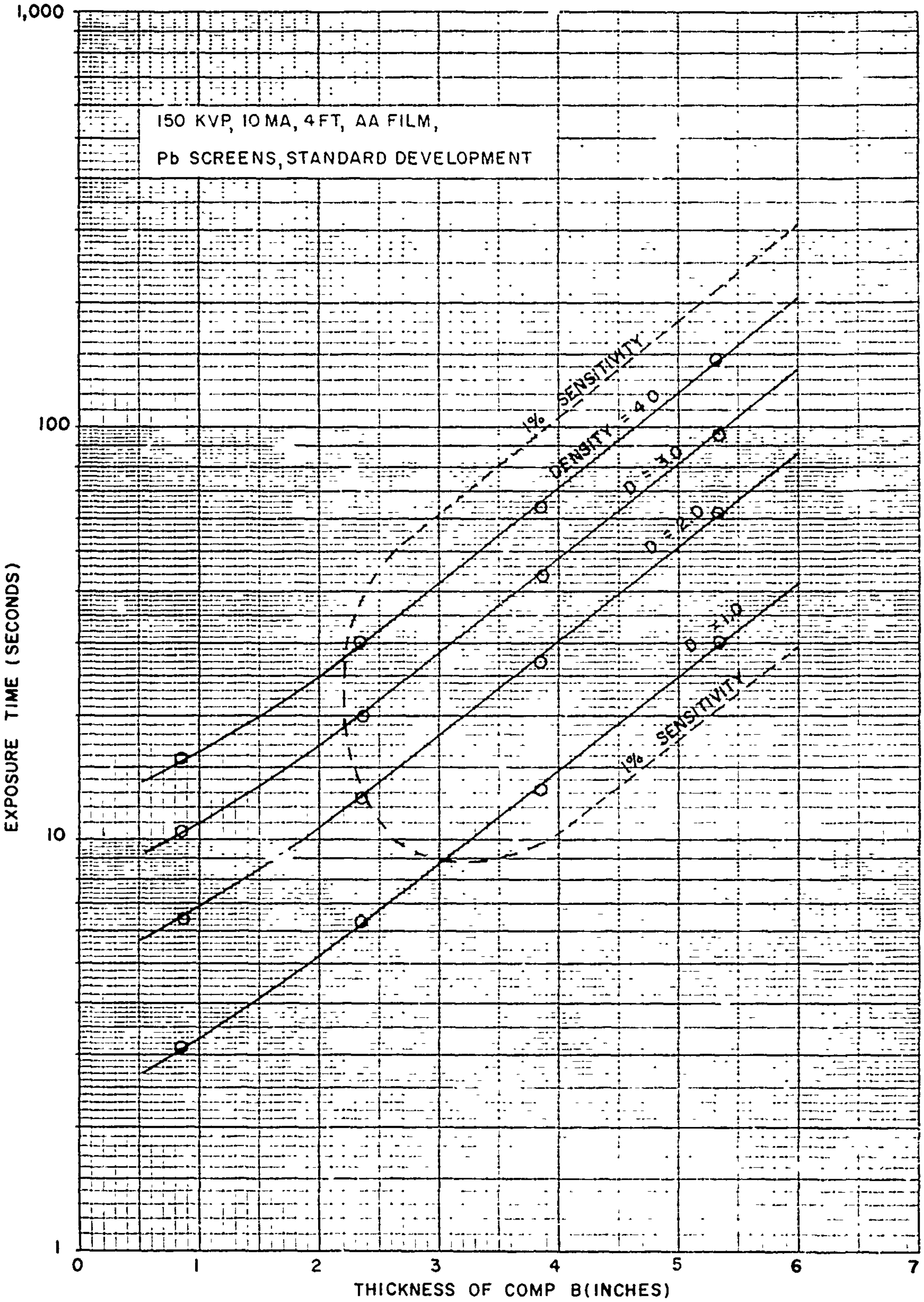

FIG. 9 TECHNIQUE AND SENSITIVITY CURVE FOR COMP B

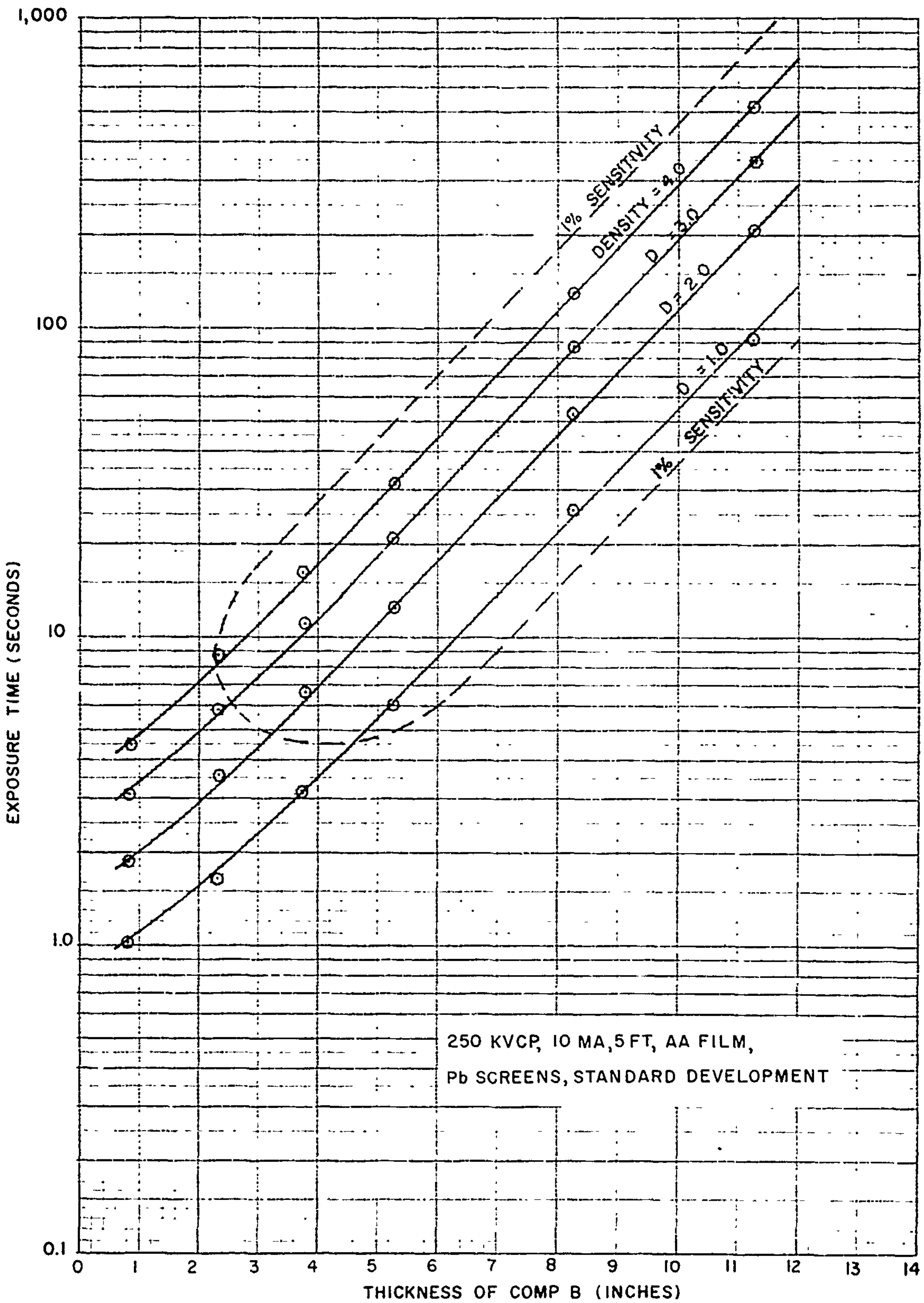

FIG. 10 TECHNIQUE AND SENSITIVITY CURVE FOR COMP B

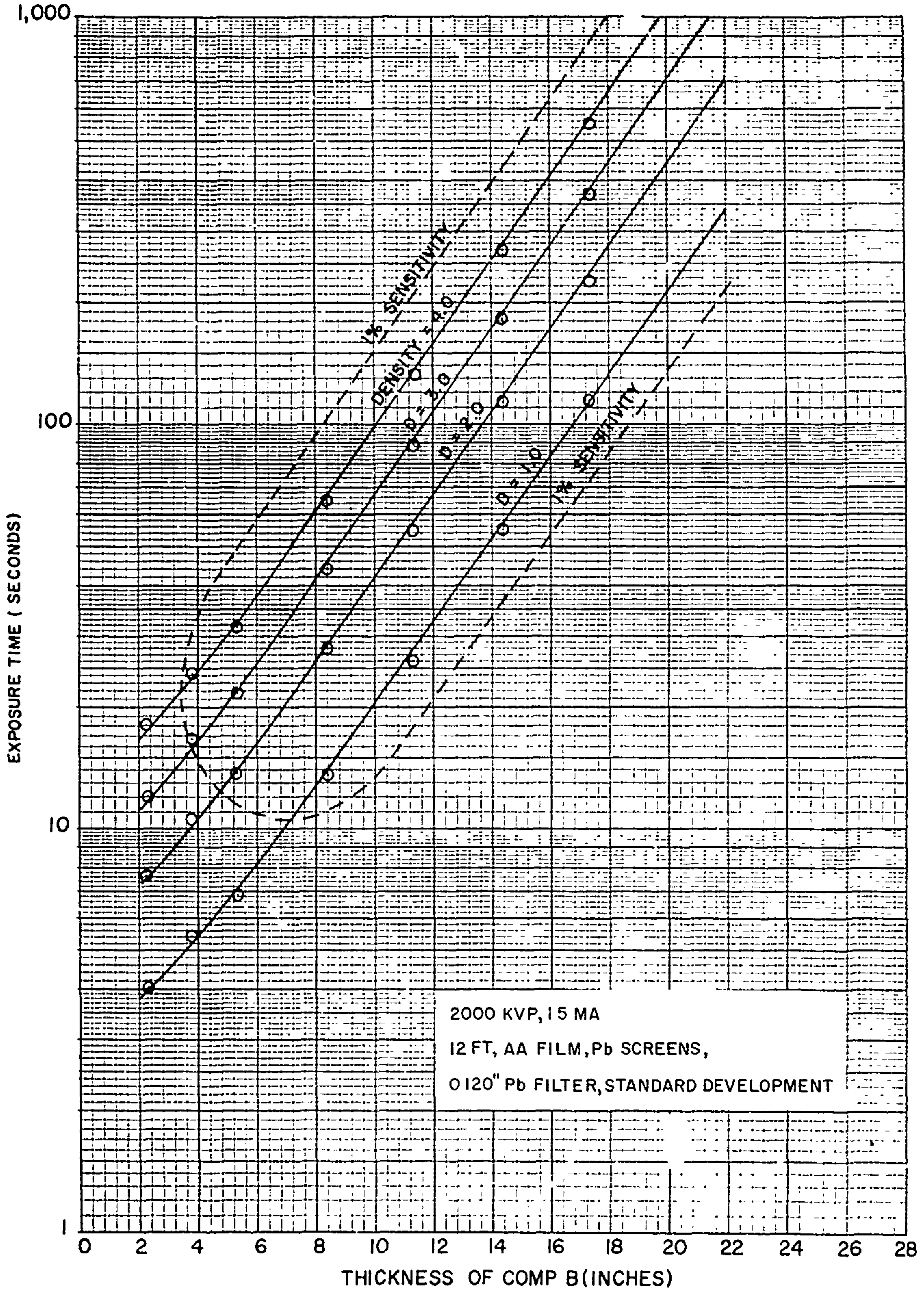

FIG. 11 TECHNIQUE AND SENSITIVITY CURVE FOR COMP B

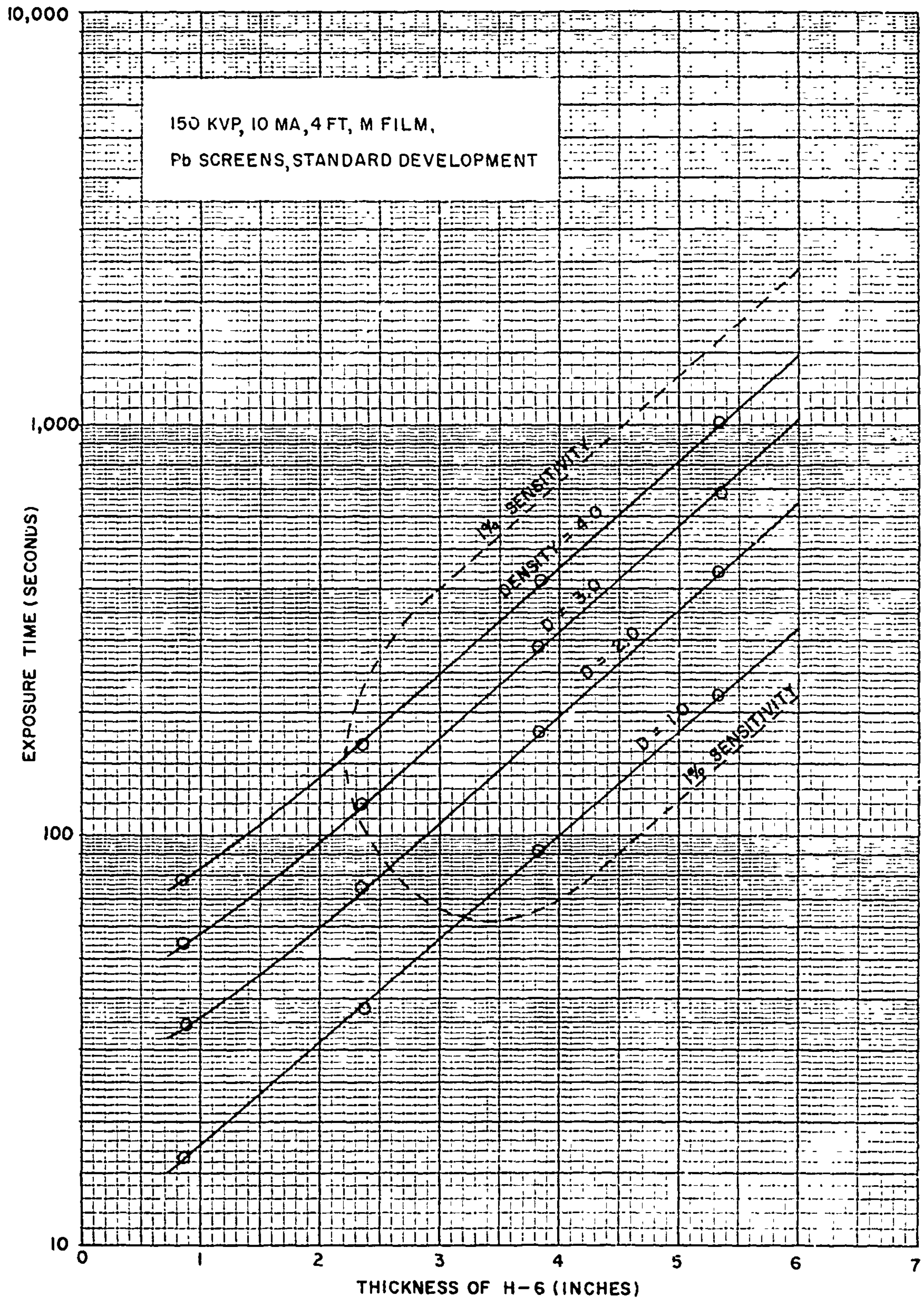

FIG. 12 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

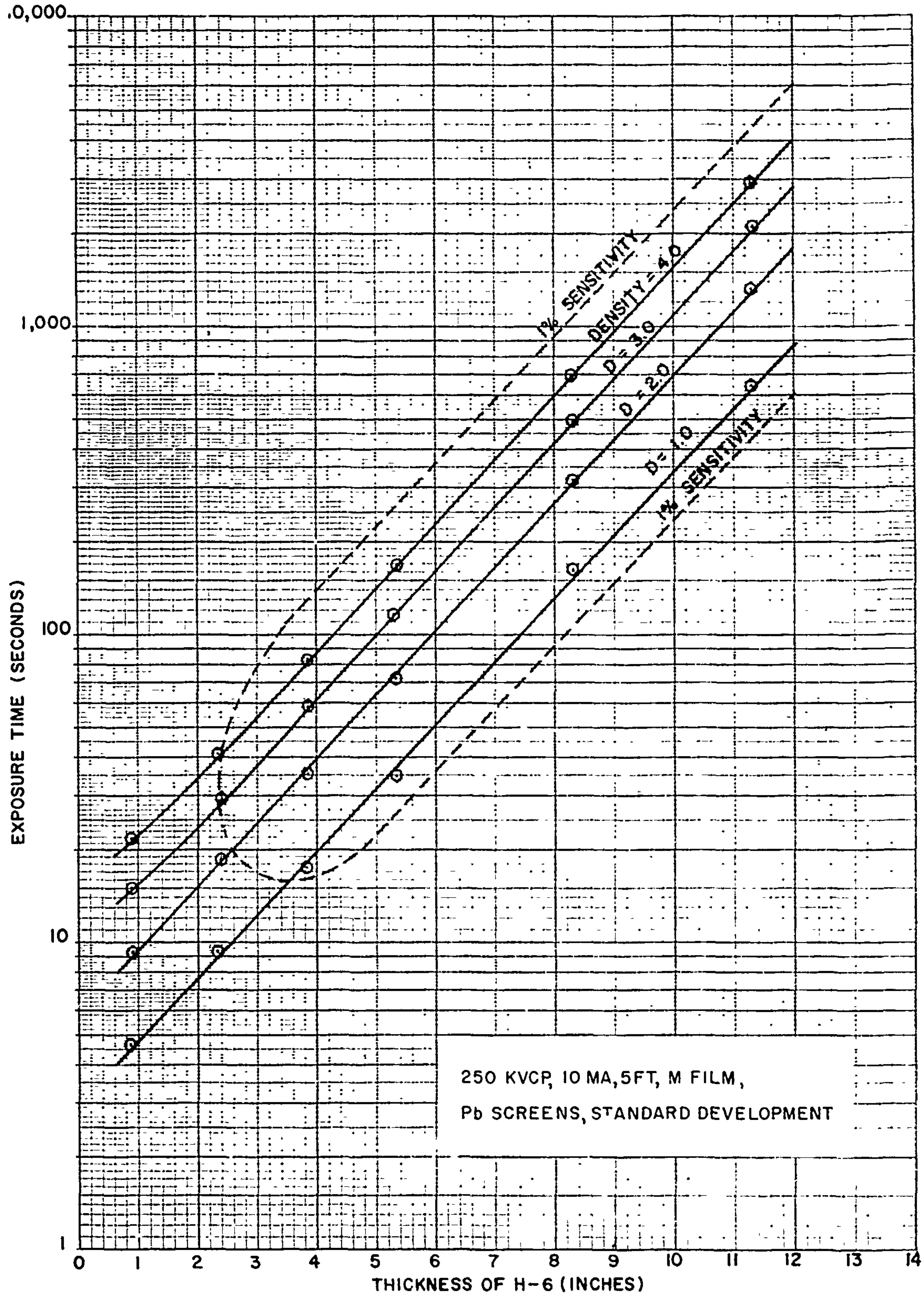

FIG. 13 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

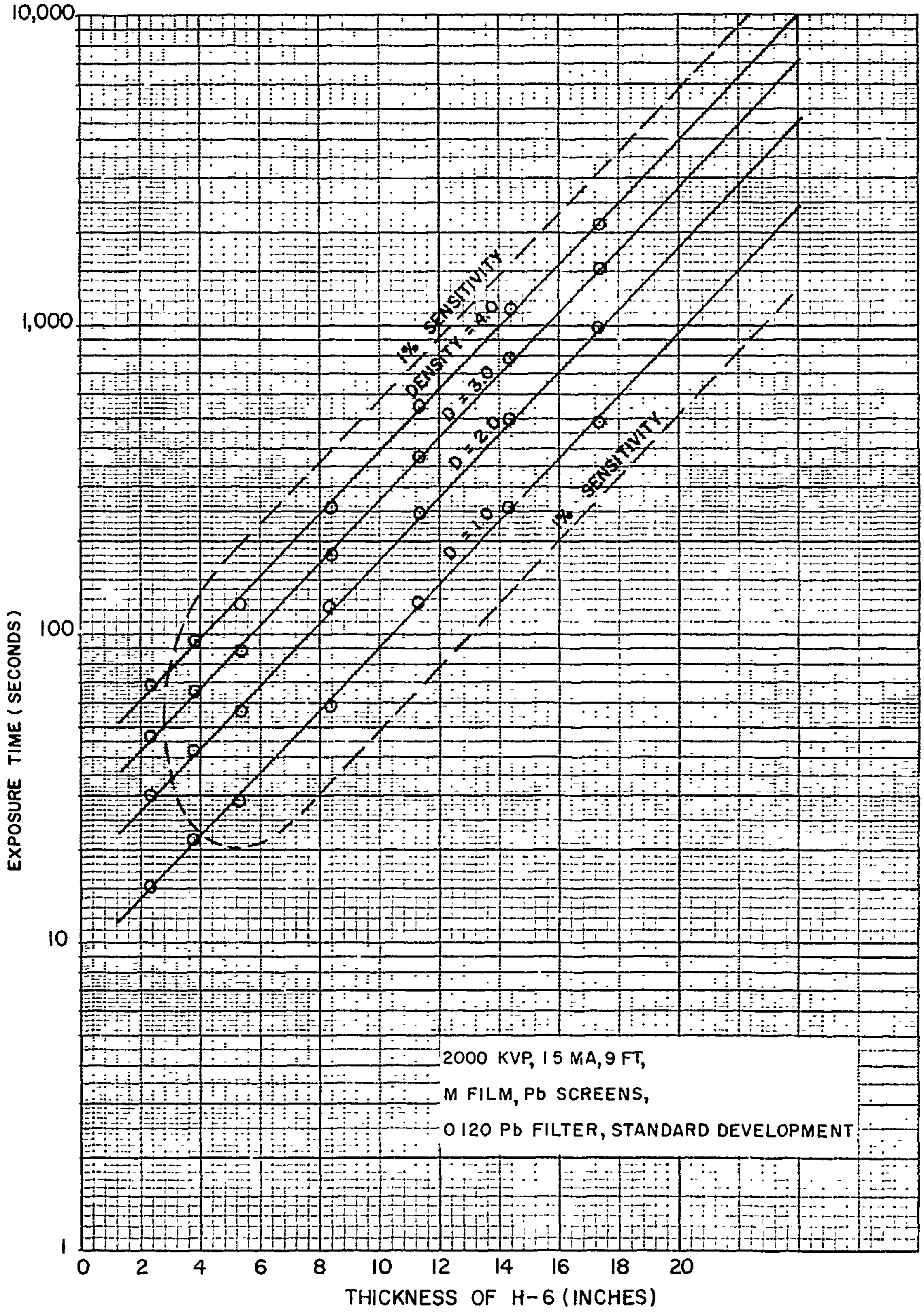

FIG. 14 TECHNIQUE AND SENSITIVITY CURVE FOR H–6

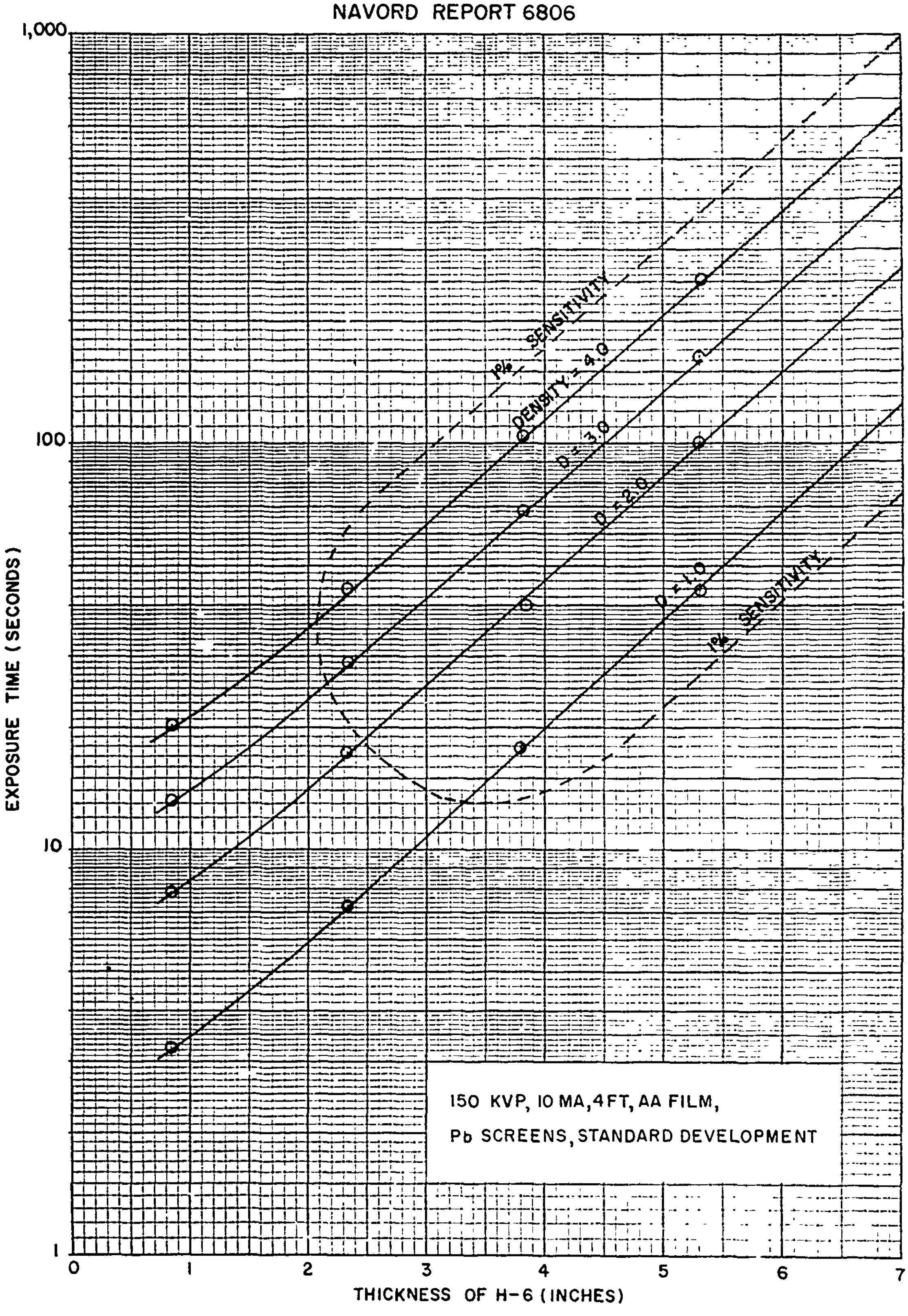

FIG. 15 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

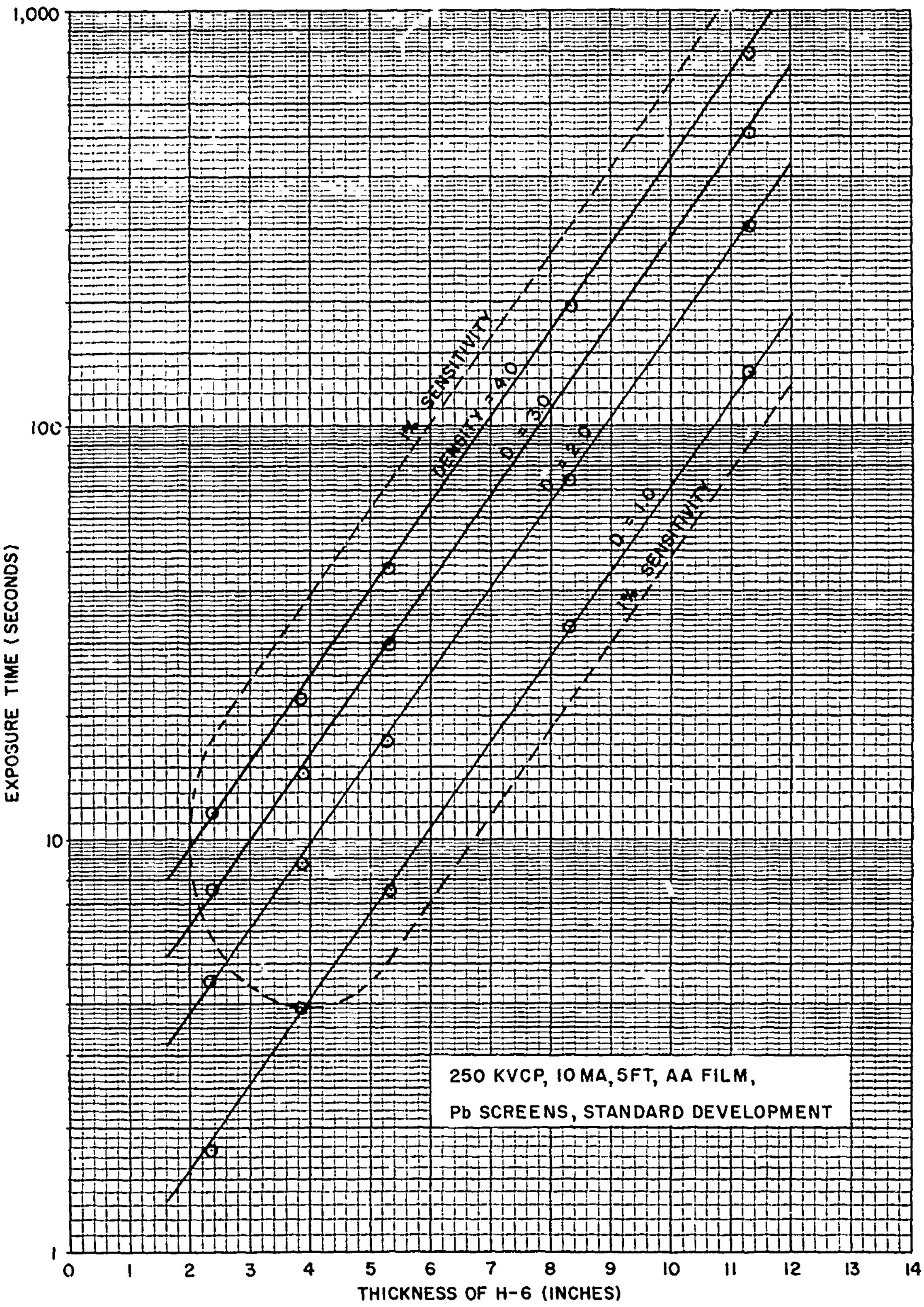

FIG. 16 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

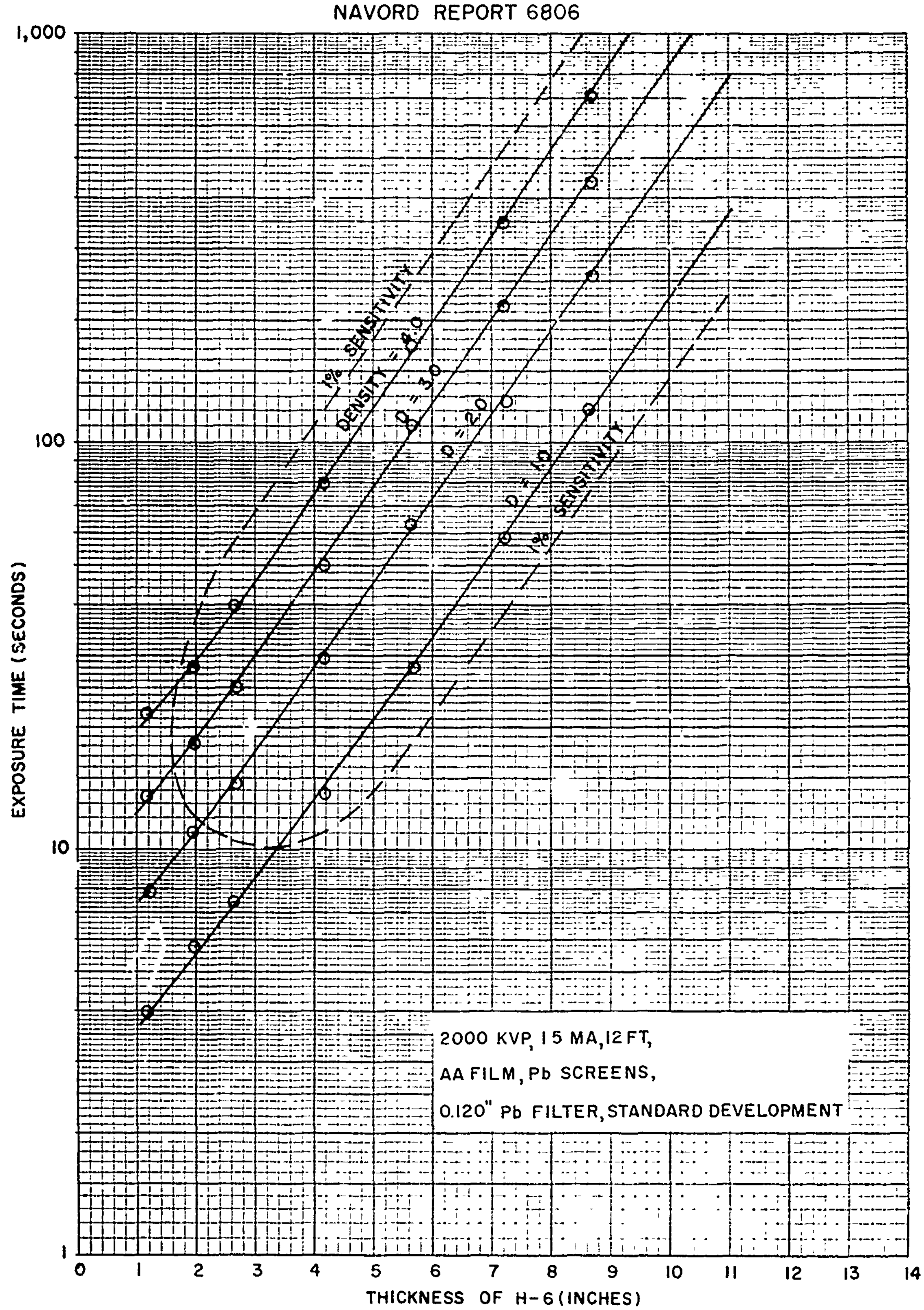

FIG. 17 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

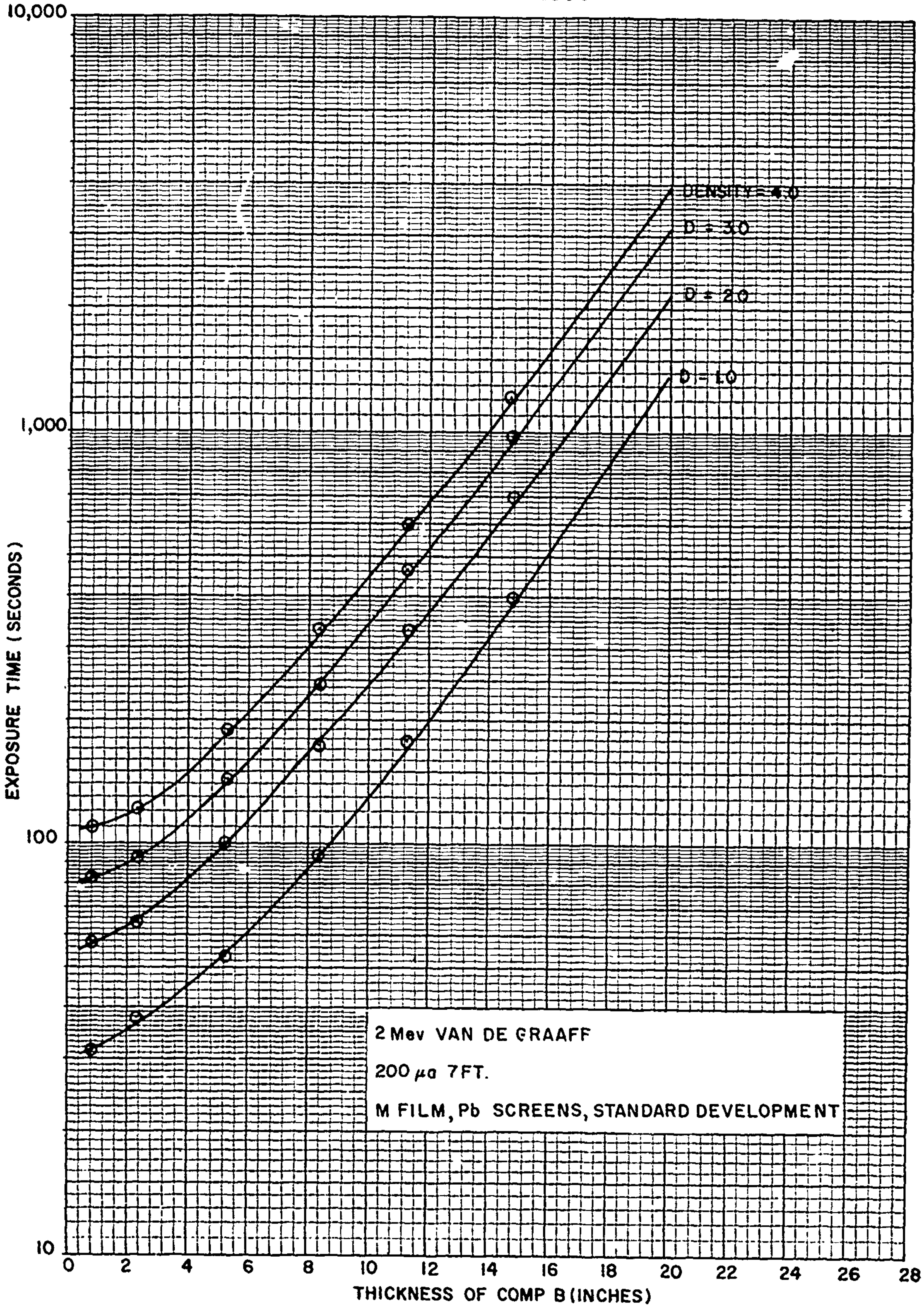

FIG. 18 TECHNIQUE CURVE FOR COMP B

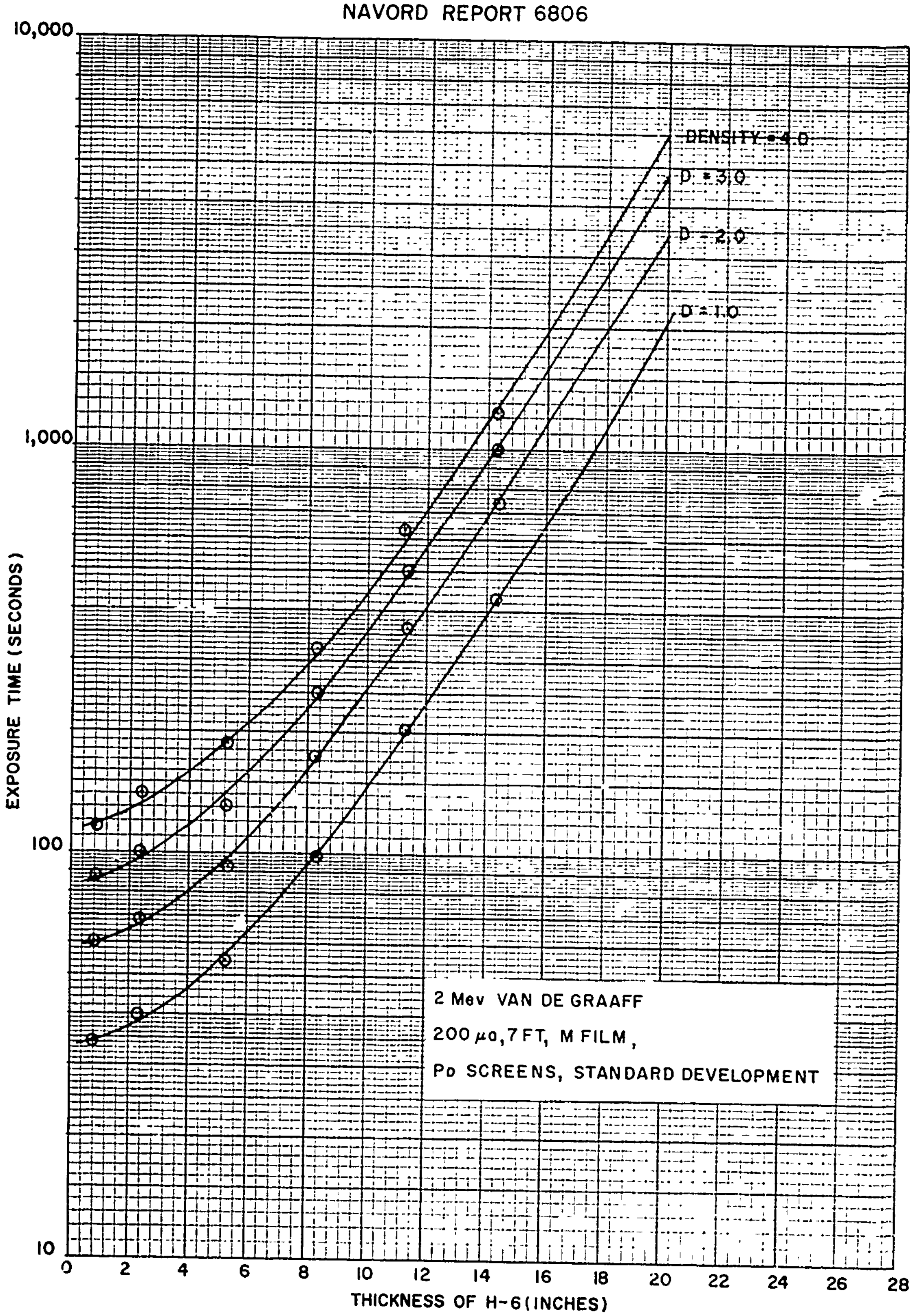

FIG. 19 TECHNIQUE CURVE FOR H-6

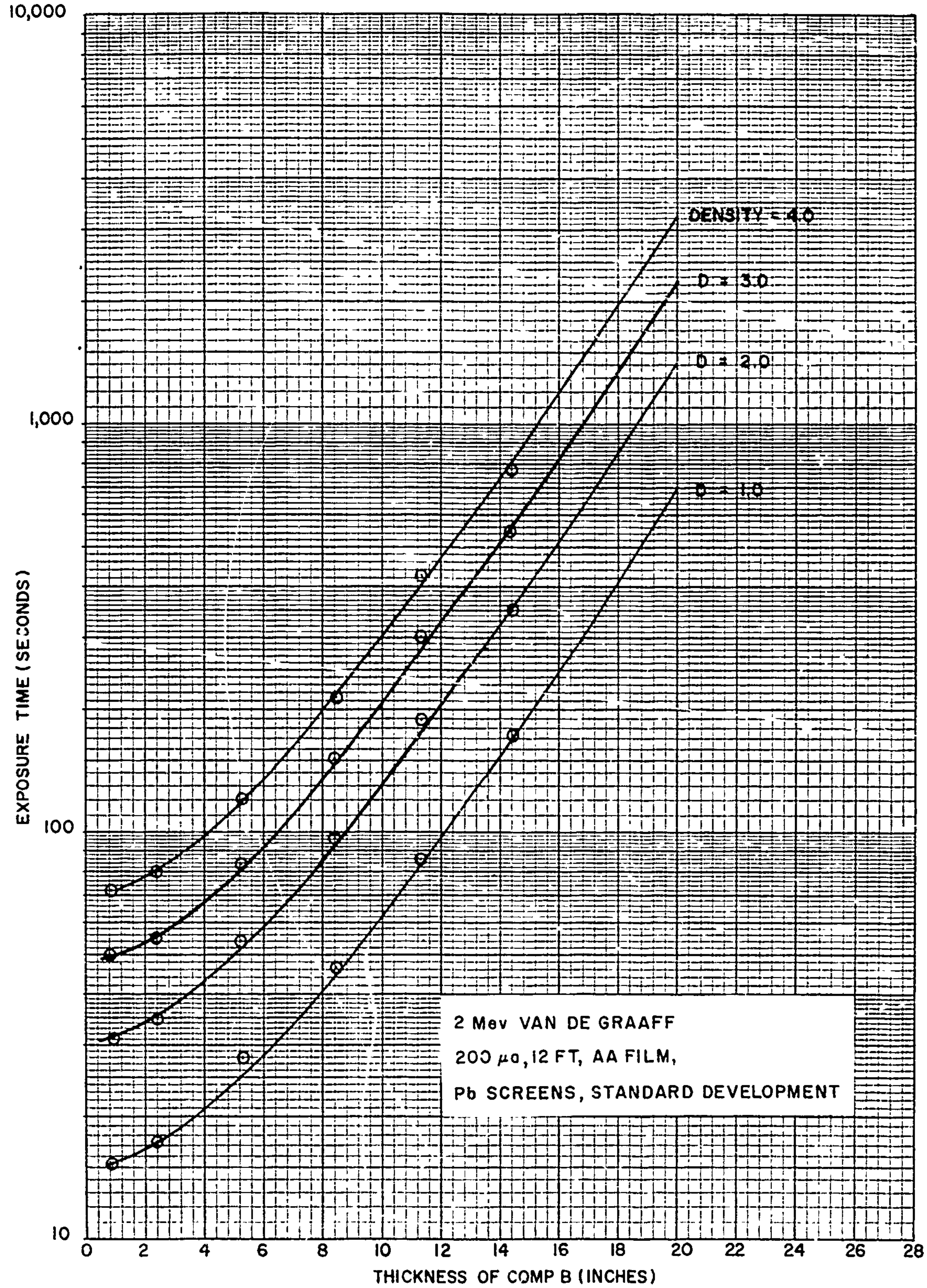

FIG. 20 TECHNIQUE CURVE FOR COMP B

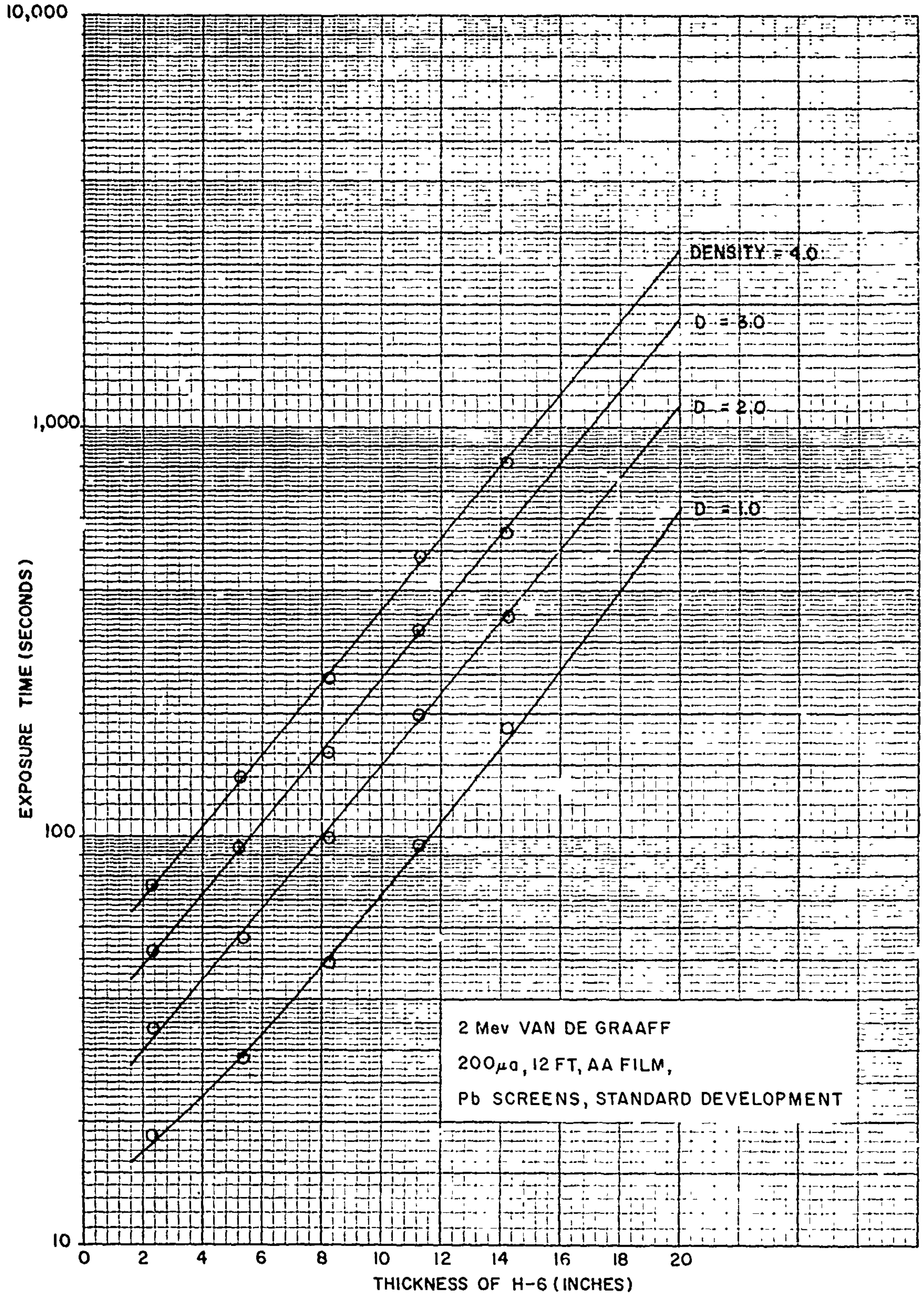

FIG. 21 TECHNIQUE CURVE FOR H-6

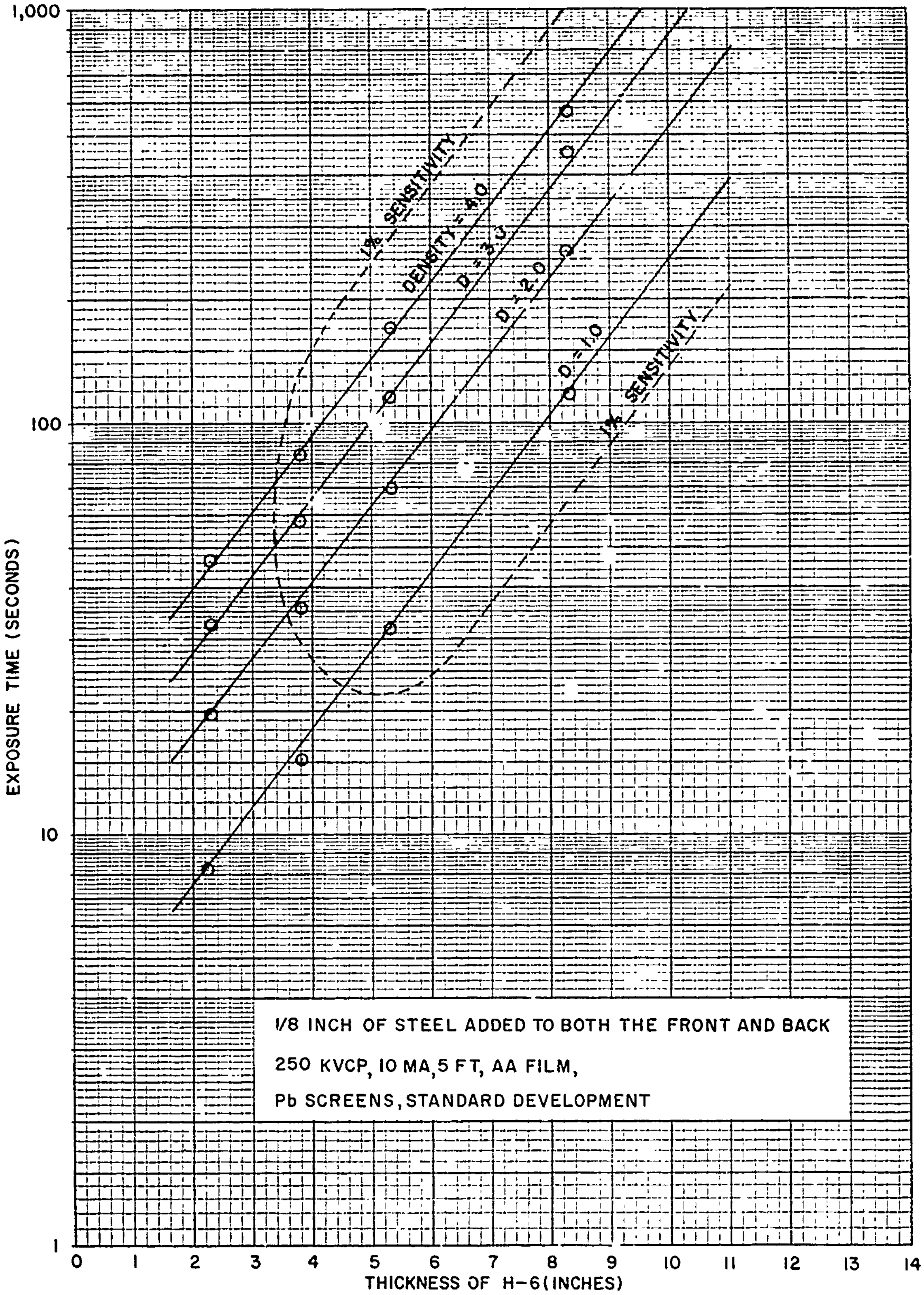

FIG. 22 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

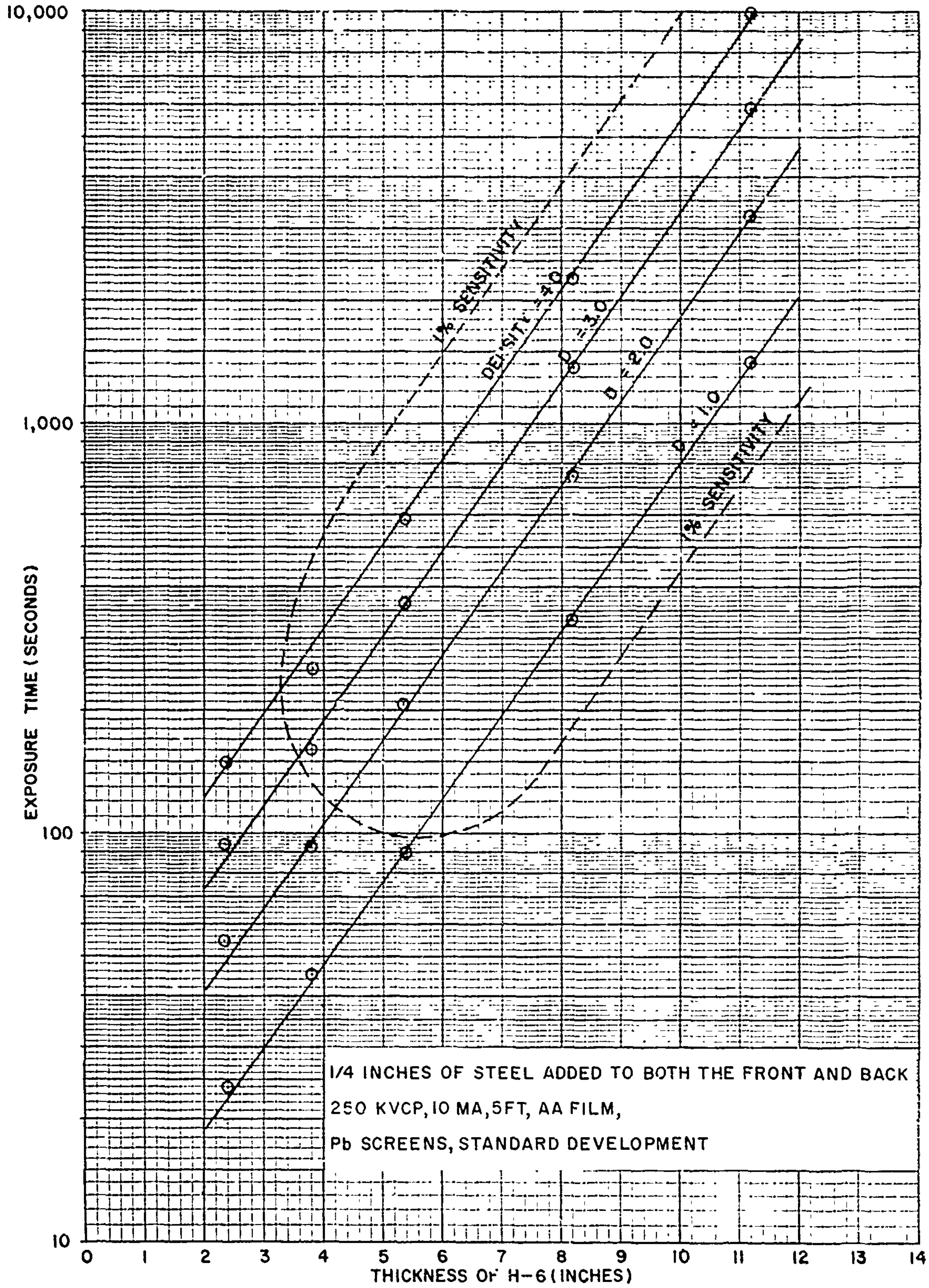

FIG. 23 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

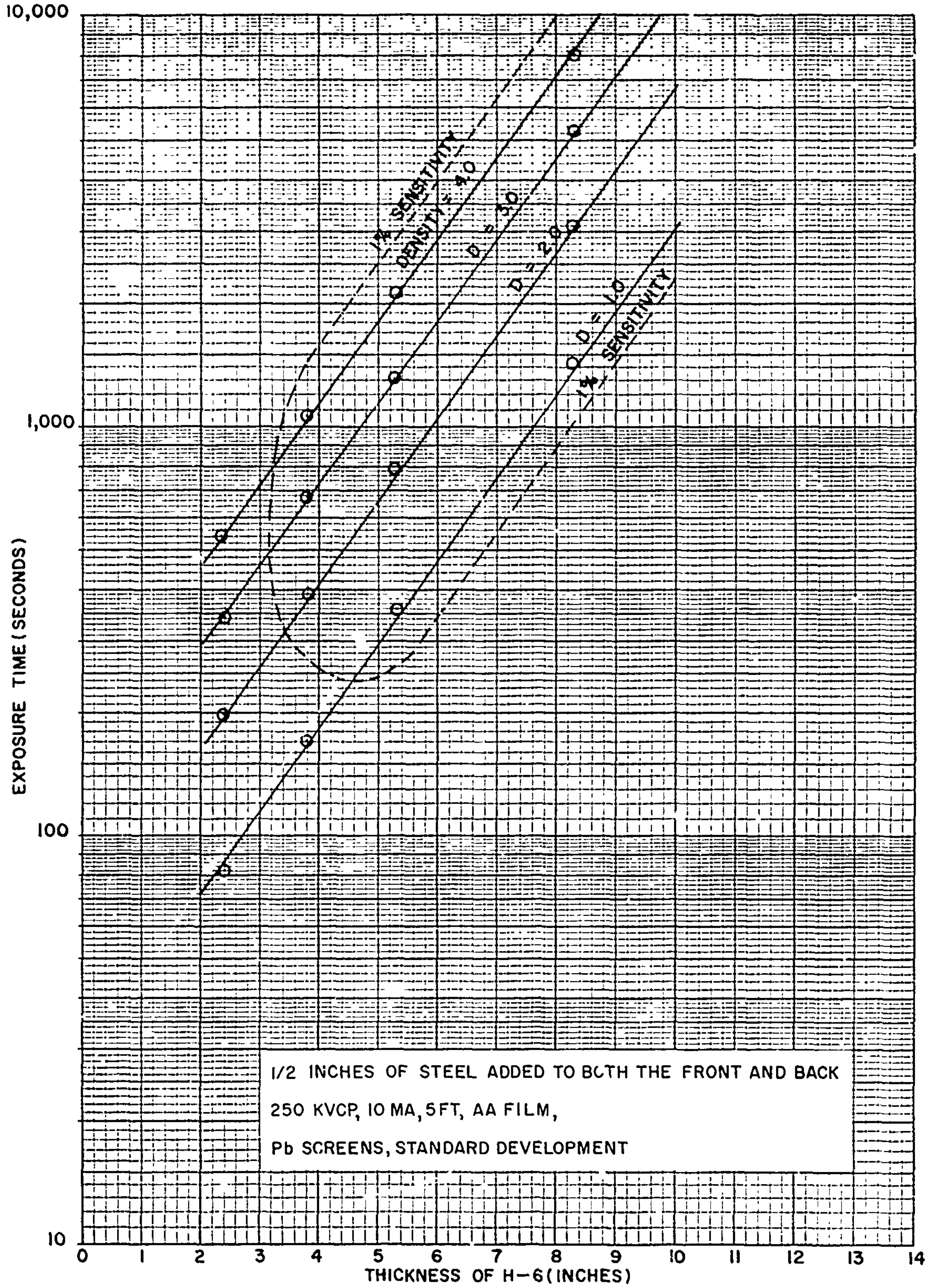

FIG. 24 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

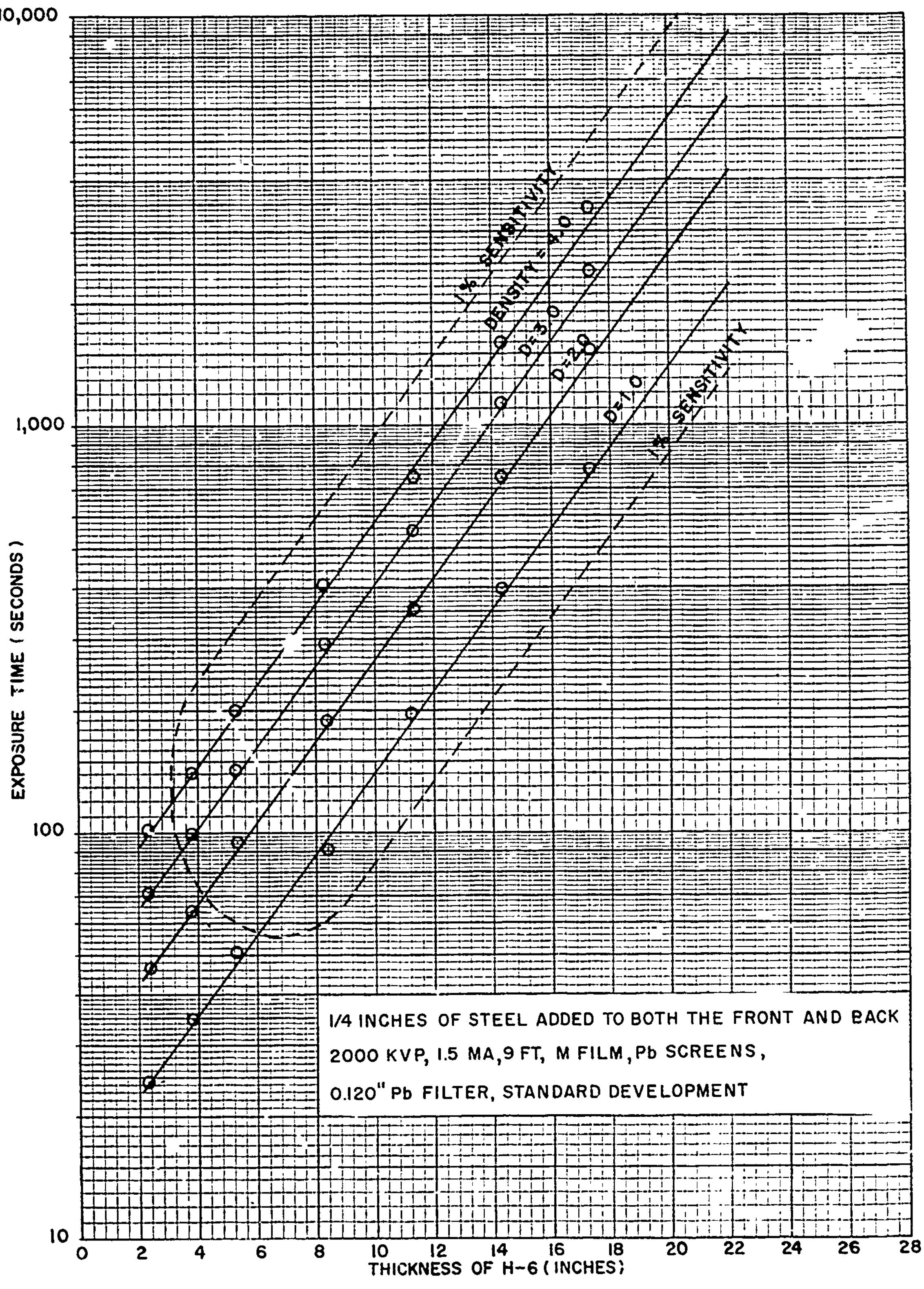

FIG. 25 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

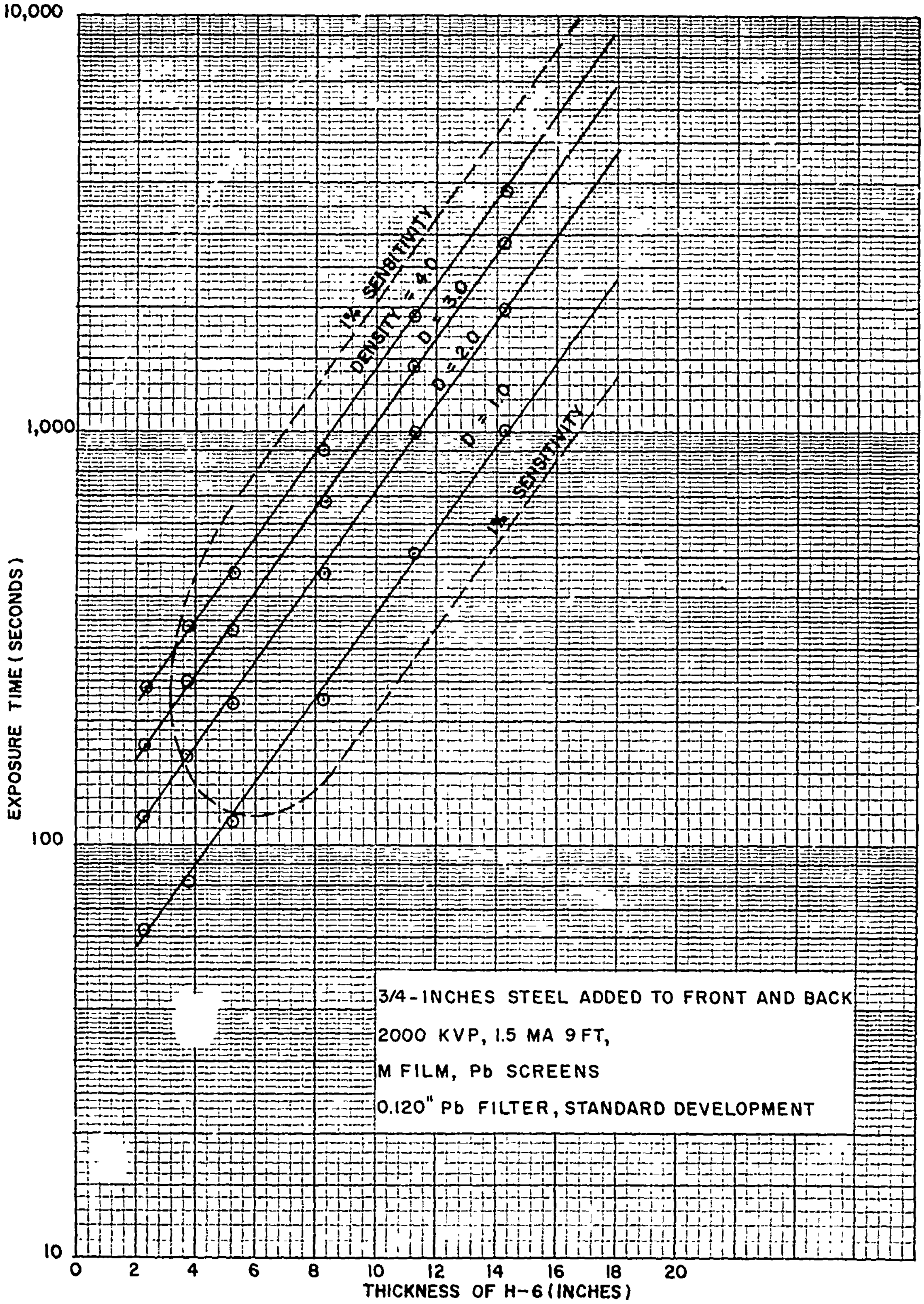

FIG. 26 TECHNIQUE AND SENSITIVITY CURVE FOR H-6

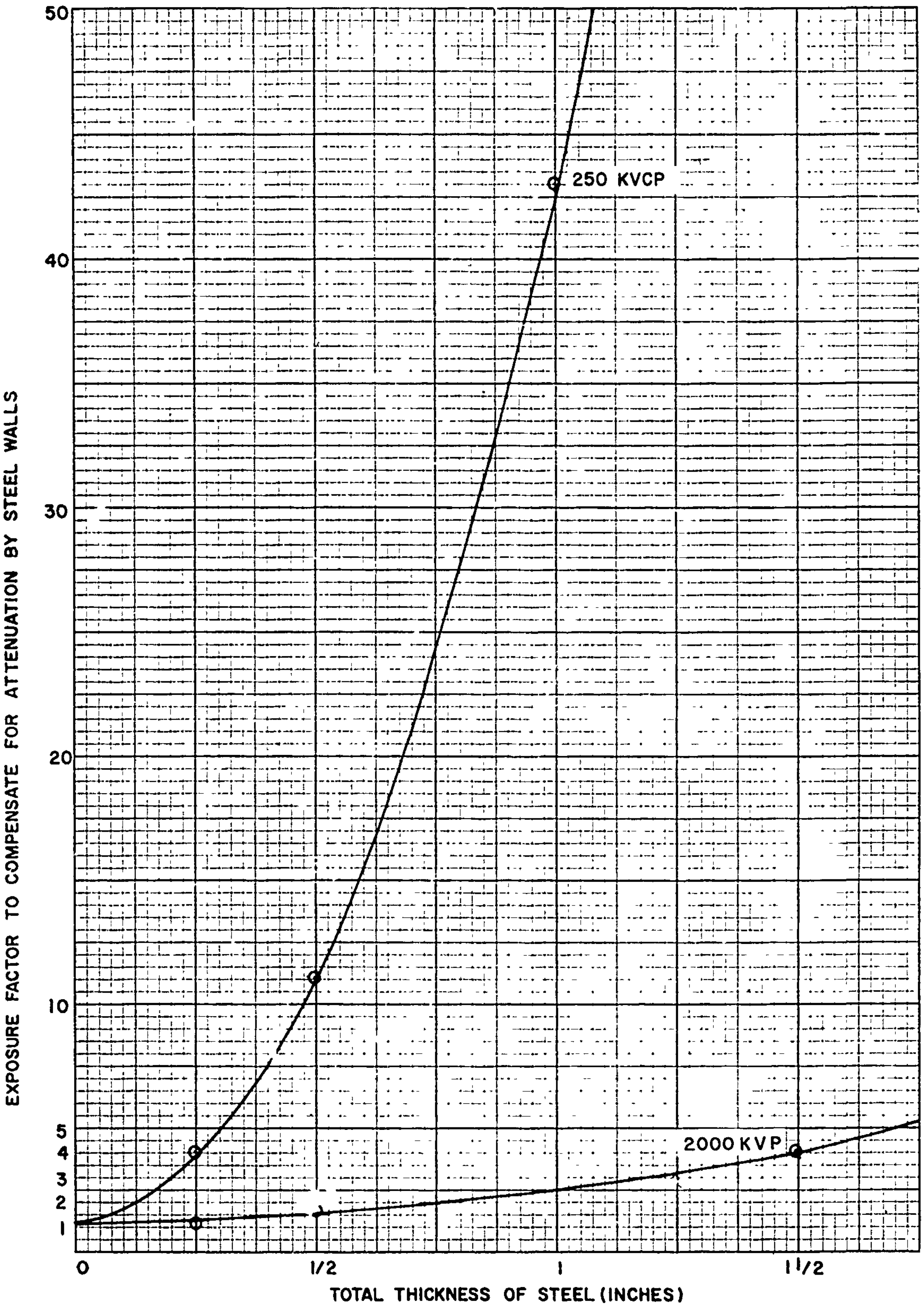

FIG. 27 EXPOSURE FACTORS TO COMPENSATE FOR ATTENUATION BY VARIOUS THICKNESS STEEL WALLS AT 250 KVCP AND 2000 KVP

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